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By Laurence Nixon

Sponsored by Naval Facilities Engineering Command

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DEVELOPMENT OF A LIGHTWEIGHT, HIGH STRENGTH, COLLAPSIBLE HOSE

ABSTRACT This report documents an exploratory development effort to produce a 6-inch diameter, lightweight, high strength, collapsible, layflat hose using aramid yarn as the hose reinforcing material. The design goals were to produce a hose with a 100,000-pound tensile strength and 1,800-psi burst pressure. The project had three phases: (1) a feasibility study, (2) manufacturing trials with 4-inch hose, and (3) the design and fabrication of 6-inch hose on the production line. The work failed to produce the desired hose primarily because of strength losses incurred in the aramid during the manufacturing process. However, the project did produce a relatively high performance polyester reinforced hose (47,000-pound tensile strength) that may have applications for fuel transfer.

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NAVAL CIVIL ENGINEERING LABORATORY PORT HUENEME, CALIFORNIA 93043

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METRIC CONVERSION FACTORS

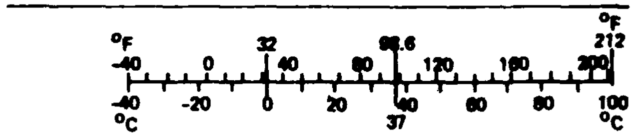
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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This report documents an exploratory development effort to produce a 6-inch diameter, lightweight, high strength, collapsible, layflat hose using aramid yarn as the hose reinforcing material. The design goals were to produce a hose with a 100,000-pound tensile strength and 1,800-psi burst pressure. The project had three phases: (1) a feasibility study,

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20. Continued

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1. Pipelines 2. Fuel hoses I. YM33-U60-091-01

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BACKGROUND

A high performance, lightweight hose is being developed under an exploratory research program. The work is directed primarily toward the ship to shore transfer of fuel during amphibious operations. The goals are to reduce the transport and storage burden by producing a lightweight, layflat hose, and to minimize installation time and support requirements through high tensile designs that reduce anchoring requirements.

OBJECTIVE

The objective of this effort was to produce a 6-inch, high strength, lightweight, layflat hose for use as a ship to shore fuel hose. The performance goals for the hose were 100,000-pound tensile strength and 1,800-psi burst pressure. Aramid reinforcing material was to be used to meet the objectives. Aramids are high strength polymers marketed by Dupont under the trade name "Kevlar."

SCOPE

A feasibility study, manufacturing trials, and a design and fabrication effort were conducted sequentially. Four-inch aramid hose jackets were woven, tested, and the results scaled to predict the performance of a 6-inch hose. A polyester jacket, based upon the preliminary aramid weave design, was woven and used to tune the extrusion line. This hose proved to be very lightweight, flexible, and had a tensile strength of 47,000 pounds (as compared to 44,000 pounds for the manufacturers best commercial product). Six-inch aramid jackets of varying designs were woven and extruded; however, none produced an acceptable product.

Appendixes A, B, and C are contractor reports that document the feasibility study, manufacturing trials, and design and fabrication efforts, respectively.

DISCUSSION

Lightweight Extruded Hose

In general, a hose consists of a tube on the inside that provides a conduit for the material passing through the hose, a carcass in the middle that provides strength, and a cover on the outside that protects the carcass and the tube. The type of hose being discussed in this report consists of a circular woven jacket (carcass) (Figure 1), that is passed through an extruder where molten polyurethane is forced through the weave under pressure and a die then forms an integral tube and cover. They are integral because they are physically connected through the interstices of the weave. The jacket is made up of longitudinal warp yarns that provide tensile strength, and circumferential weft yarns that provide hoop strength. The circular loom on which the jackets are woven can be adjusted to vary the number of warp yarns, the amount of weft in a given length, and the way that they are interwoven in order to produce different jacket designs. The jacket design, the yarn material, the characteristics of the twisted yarn, and the diameter of the hose will determine the performance of the finished product. Typical jacket materials are polyester and nylon.

Feasibility Study

The purpose of the feasibility study was to determine pitfalls, obstacles, and the practicality of using aramids in a circular woven hose jacket. The study established that the basic properties of aramids (chemical, thermal, and physical) should permit them to be used in the hose manufacturing process; however, there were three areas of concern. The concerns were: (1) a very high modulus of elasticity and thus very low extensibility, (2) sensitivity to ultraviolet radiation, and (3) poor performance in compression and fatigue. If these could be worked around or resolved, the study indicated that the performance goals of 100,000-pound tensile strength and 1,800-psi burst pressure could be achieved. Because of these concerns and the high cost of aramids, it was decided to first produce 4-inch diameter samples of hose. This would prove the feasibility and provide information and experience before attempting a 6-inch design.

Manufacturing Trials

Two 4-inch jackets were designed. The first had aramid warp and weft yarns and had a 2,700-psi burst pressure which, when scaled to a 6-inch hose, would yield the desired 1,800 psi. The second jacket had aramid warp, polyester weft, and, when scaled to 6-inches, would theoretically result in a 750-psi burst. The purpose of the second jacket was to act as a control and to determine how aramid and polyester would interact when woven together. Both jackets had aramid warp and should therefore have the same tensile strength.

The first step was to twist the aramid into yarns of the desired gauge or "denier." The warp yarns were twisted first using standard techniques and production speeds. The makeup efficiency, which is a measure of the strength loss suffered during twisting, was 68 percent (i.e., 32 percent loss), which is poor. After trying a number of different techniques, the aramid weft yarn reached an acceptable makeup efficiency of 88 percent. The jackets were woven without difficulty.

The hose extrusion process is one that involves a startup period during which significant amounts of jacket are used up while the extrusion head is tuned. For this reason, the short lengths of jacket produced were given a glued in tube and a sprayed on polyurethane cover. The finished hoses were tested for tensile strength and burst pressure. Both hoses exceeded the performance targets for burst pressure. The tensile strengths, however, were only about 64 percent of the targeted 100,000 pounds. This was attributed primarily to the poor makeup efficiency of the warp yarn. Analysis indicated that if the efficiency of the warp yarns was increased by twisting in the same way as the weft, and the jacket design was modified slightly, then the 100,000-pound tensile target would be feasible. The work moved into 6-inch design and fabrication of an all aramid, high performance hose.

Design and Fabrication

The design effort started with the selection of a coating for the aramid yarn. Aramids tend to be hydrophilic because they readily absorb moisture from the atmosphere. As previously stated, they are also sensitive to fatigue and compression. These are problems in a manufacturing process where weaving repeatedly flexes the yarns and where any retained moisture flashes to steam as the jacket enters the hot extrusion head. The yarn coating was intended to minimize the amount of moisture absorbed by the yarns and to protect them somewhat during the weaving process. Two coatings, an isocyanate and a polyurethane, were evaluated. The polyurethane was selected based on tests for moisture regain.

The jacket design and yarn selection were derived from the information gathered during the feasibility study and manufacturing trials. A polyester jacket based on the proposed aramid weave design was woven and successfully extruded. The hose had an adequate burst pressure (550 psi) and an unexpectedly high tensile strength (47,000 pounds). Figure 2 shows this hose, on the left, next to a high performance commercial product which has a tensile strength of 44,000 pounds. Note the difference in wall thicknesses.

Kevlar 29 was selected for the aramid jacket to get the best possible elongation and moisture retention characteristics. The twist of the yarn was an important factor in the design because the degree of twist will influence fatigue life and extensibility. It has been shown that high twist levels in aramids generally increase fatigue life and extensibility and decrease strength. The design wanted to maximize all three, so the objective was to maintain minimum strength requirements at the highest possible twist levels in order to maximize fatigue life and extensibility. The warp yarn was a 1,500 denier, 5-ply cabled construction. As illustrated in Figure 3, cabling means that the individual plys are twisted in the opposite direction as the five that make up the finished yarn. Each ply had 3.3 twists per inch in the clockwise direction. Five were then twisted together at 2.8 twists per inch in the counterclockwise direction. The weft yarns were 2,250 denier, 5-ply cabled of varying twist levels.

A length of jacket was woven and extruded. As shown in Figure 4, the attempt ended with extensive blistering of the hose as it left the extrusion head. This meant that some substance in or on the jacket was flashing to gas as it came into contact with the hot plastic. An analysis in the lab indicated that the problem was not moisture but finishing oils used in the manufacture of the Kevlar. The temperature at which the jacket was dried just before entering the extruder was increased to drive off the oil, and a length of hose was successfully extruded. The short length burst pressure of this hose was 1,050 psi. The predicted burst was 1,966 psi indicating a 46 percent loss.

By pulling weft yarns from the hose jacket during various stages of production and testing them in tension, the sources of the losses were determined. Results indicated that weaving (12 percent), high temperature drying (11 percent), and drying under high crimp (10 percent) accounted for 33 percent of the strength loss. A yarn is crimped (bent) as it is woven between the other yarns in the jacket. The initial jacket design was a twill weave or 1 up/2 under, meaning that the warp yarns pass over one weft and under two, over one, under two, etc. The large number of resulting bends is described as high crimp. By going to unconventional weave patterns such as 1 up/5 under, both the crimp and the fatigue on the yarn as it was woven would be reduced, in theory reducing the strength loss. Figure 5 illustrates a twill weave and a low crimp weave. Attempts were made to extrude two "low" crimp jackets without success. In one case the jacket was too tight and the molten urethane could not penetrate the weave to form a tube. In the other case, the extrusion dies could not be adjusted to accommodate the unusual weave pattern. At this point materials had been exhausted and work was stopped.

CONCLUSIONS

The project was unable to produce the desired hose because of losses in strength suffered by the aramid during twisting, weaving, and drying of the yarns. Alternative designs were considered that reduced the weaving fatigue and crimp of the yarn; however, these could not be extruded with existing tooling. With more work some or all of these obstacles may have been overcome; however, other characteristics of an aramid reinforced hose became evident during the course of the project. The hose would have been extremely stiff and therefore difficult to handle. When forced into tight bends as would inevitably happen, the inner yarns would be in a state of compression thus weakening the hose each time it was bent. Because of its low extensibility, the hose is unable to absorb much energy by expansion and so typical water hammer would give rise to very high pressure surges. It is not inconceivable that the required safety factor would reduce the working pressure close to that of an ordinary polyester hose. Some work was done on jackets that used both polyester and aramid. It might be possible to produce a hose with aramid warp and polyester weft that could expand enough to accommodate water hammer and still have high tensile strength.

RECOMMENDATIONS

The lightweight, high tensile polyester hose produced when calibrating the extrusion head for the aramid would be a good candidate for a lightweight or flyaway fuel system. It may also be suitable as a floating hose or have applications for ship to ship service. Its advantages are: its light weight (1.3 lb/ft as compared to 6.3 lb/ft for hose produced under MIL-H-22240, "Hose, Rubber, Petroleum Based Fuels and Water Services, Discharge Only, Smooth Bore, Lightweight Bouyant Type 11); its high strength (47,000 pounds); and its extreme collapsibility. This results in more hose on a given reel. Its weaknesses are vulnerability to kink and twist. Some coupling development may be necessary in order to pick up the full tensile strength of the hose.

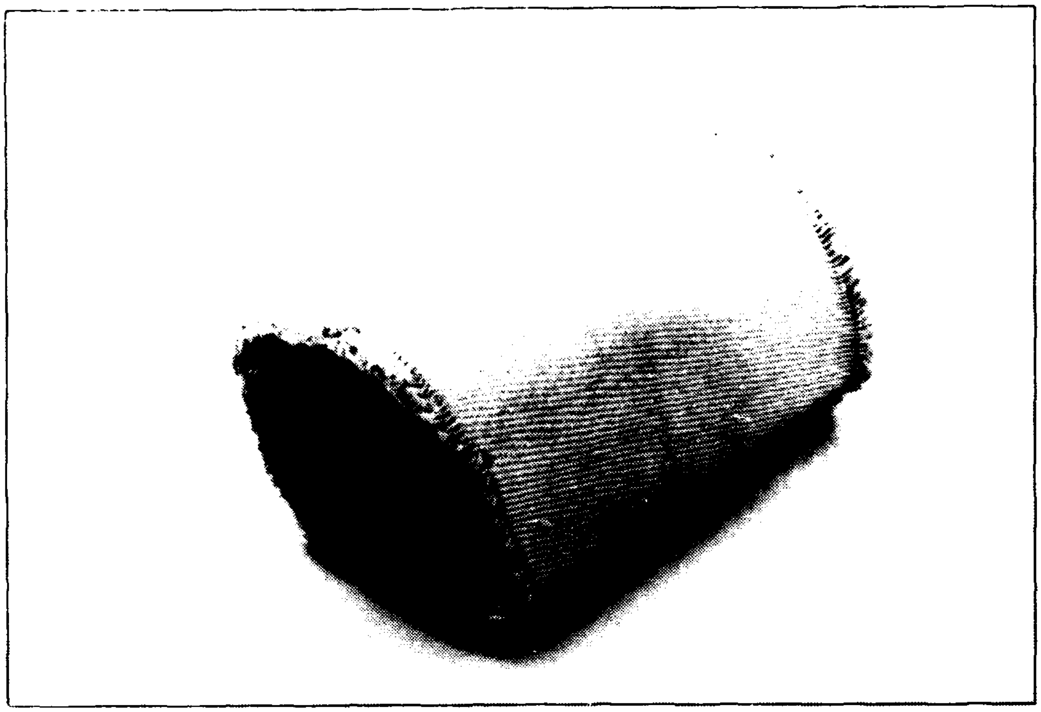


Figure 1. Circular woven jacket.

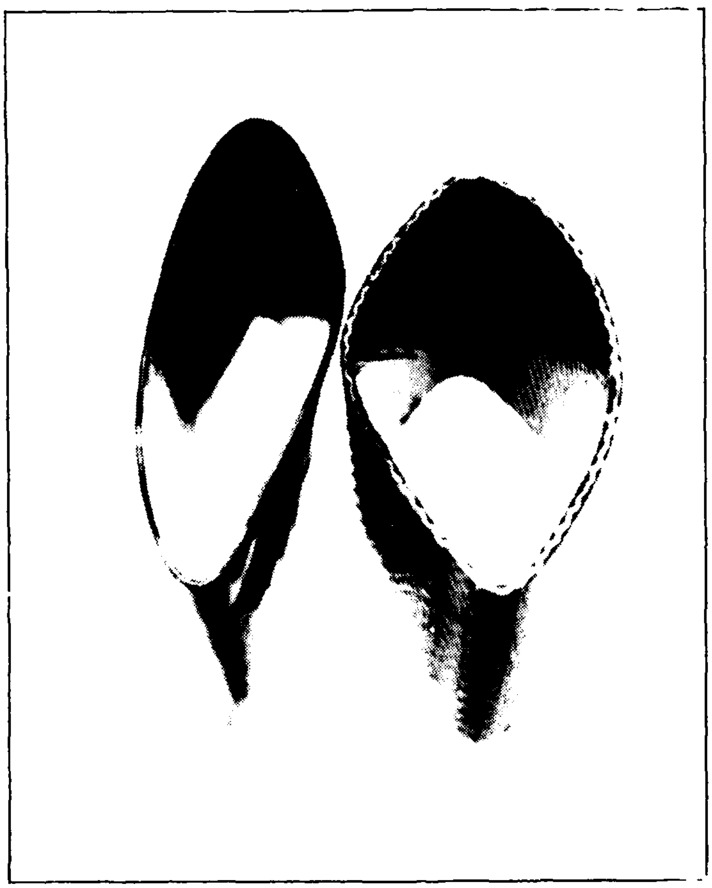


Figure 2. Experimental and commercial high performance lightweight hose.

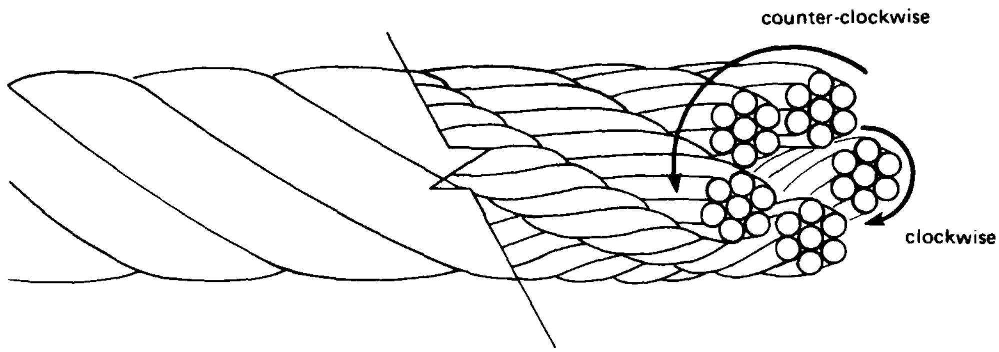


Figure 3. Cabled yarn – plys twisted opposite direction of finished yarn.

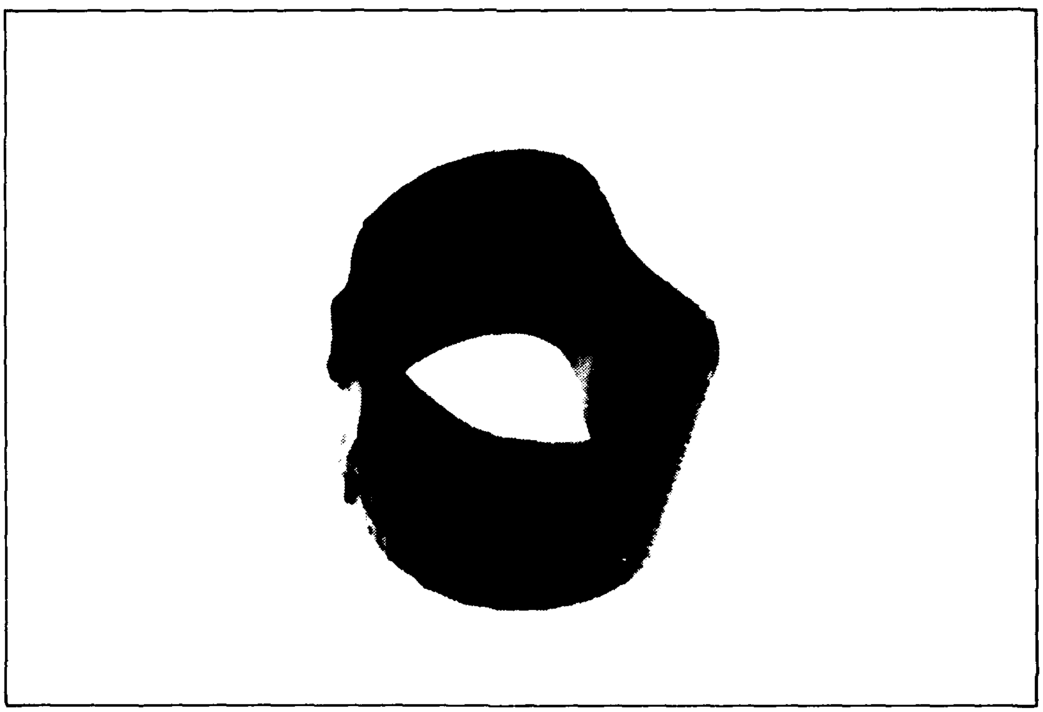
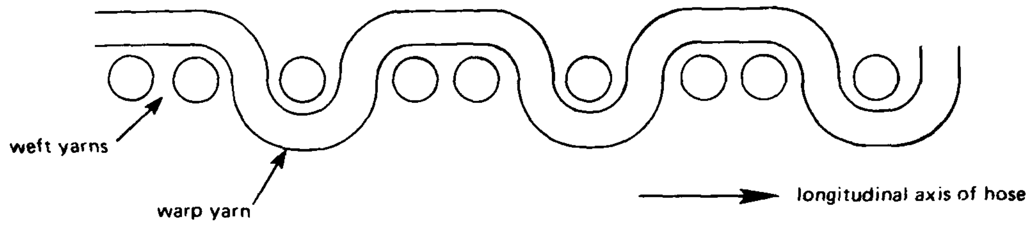
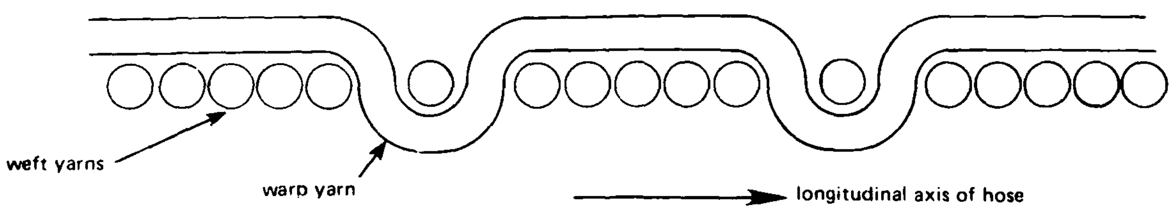


Figure 4. Blistered Kevlar hose.



– conventional twill weave, 1 up/2 under (high crimp)



-unconventional weave, 1 up/5 under (low crimp)

Figure 5. High and low crimp jacket weaves.

Appendix A

FEASIBILITY STUDY ON THE USE OF ARAMID YARNS IN HIGH PERFORMANCE LAY-FLAT HOSE

ANGUS FIRE ARMOUR CORPORATION

FEASABILITY STUDY ON THE USE OF ARAMID YARNS IN HIGH PERFORMANCE LAY-FLAT HOSE

Prepared For:

Naval Civil Engineering Laboratory
Port Hueneme, CA 93043

Under Contract Number:

N-62474-84-C-3144
Phase II, Part II, Item 4.3.1.

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ARAMIDS AND THEIR USE IN LAY FLAY/SEMI LAY FLAT HOSE

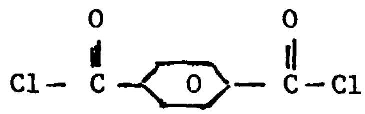
1. ARAMIDS

1.1. Chemical Nature

Aramids, or more correctly, aromatic polyamides, consist of chain molecules of poly-p-phenyleneterephthalamide, the latter forming long rigid chains. The long rigid chains are a pre-requisite for superior fibre properties.

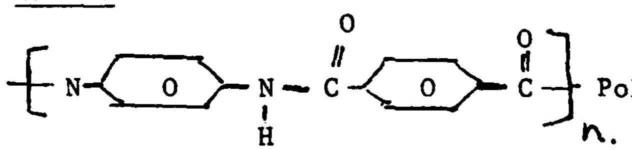
Raw Materials.

p.Phenylenediamine (PPD)



Terephthaloyldichloride (TDC)

Chains



Poly-(paraphenylene terephthalamide)

The molecular rigidity of the hexagonal rings, together with weaker intermolecular bonding results in a stiff "ladder" polymer of high strength and tensile modulus.

1.2. Aramid Fibre Production

Aramid fibres are produced using the wet spinning method:

Monomers → Polymerization ← Solvent

↓

Coagulation, extraction, drying

↓

H_2SO_4 → Dissolving

↓

H_2O → Spinning

↓

Washing, neutralizing, drying

↓

Winding

For specific applications after treatments are incorporated in the process e.g. a dip treatment with epoxy resin and RFL to promote yarn adhesion.

1.3. Suppliers

Aramids are currently manufactured by only two companies, these are, with trade names:

TWARON: A Dutch product manufactured by Aramide Maatschappij Vof, a joint venture of Enka b.v. and N.V. Noordelijke Ontwikkelingomaatschappij Nom. Enka b.v. handle the marketing of Twaron and provide the technical support to purchasers.

KEVLAR: An American product manufactured by E.I. Du Pont de Nemours and Co. (Inc).

The two yarns are virtually identical with only very slight difference in physical properties and where applied, finishes. For the purpose of this report the two fibres will be considered to be identical, and their properties reported under the generic name "Aramid".

1.4. Chemical Properties

Aramids are, in general, highly resistant to most chemicals. Due to their high crystalinity they have low accessability, preventing chemicals from diffusing into the polymer. This however means that it is very difficult for polymers, rubber, etc. to adhere to the Aramid which can cause problems in hose manufacture, as we will see later. Prolonged exposure to acids and alkalies or to materials releasing them gives rise to strength losses.

Figures 1.4.1., 1.4.2. and 1.4.3. give details of Aramid resistance to certain chemicals (Ref. 1).

Aramids are affected by exposure to U.V. light. For example after 200 days exposure to day light the strength of an Aramid yarn is reduced by ca 50% (Ref. 1). Figures 1.4.4. and 1.4.5. show the effect of U.V. exposure (Ref. 1). Work done by C. Gourdin (Ref. 2) has shown that Aramid fibre exhibits good resistance to salt spray, sea water, solvents and grease, but that U.V. degradation can be extensive. J.R. Brown et al (Ref. 3) has shown that photochemical degradation of Aramid can vary from batch to batch of fibre, and that the rate of degradation may be determined by small variations in the degree of crystallinity in the fibres.

1.5. Thermal Properties

Because of its rigid, chemically stable chains and high crystallinity, Aramid exhibits a high thermal stability. Long term exposures up to 250°C result in relatively low decreases of the original properties. Short term exposures up to 450°C can be tolerated without high strength losses (Ref 1). Aramids exhibit close to zero shrinkage at 160°C. (Ref. 4).

1.5. Thermal Properties (continued)

They neither melt or support combustion and only begin to carbonize at 425°C (Ref. 4). They show no embrittlement or loss of strength even at temperatures as low as -70°C. (Ref. 4).

Figure 1.5.1. gives details of strength loss versus temperature (Ref. 4).

1.6. Physical Properties of Yarns

Aramids have the highest strength to weight ratio of any commercially available, organic, fibre, some 2 to 3 times higher than nylon and polyester. They also have a strength weight ratio some 5 times higher than that of steel. The extension at break of Aramids is 3 - 4% compared to 12 - 20% for polyester and polyamide. Figure 1.6.1. (Ref. 4) shows typical comparative tensile properties of some textile materials. As can be seen from figure 1.6.1. (Ref. 4) Aramids also have a very high extension modulus. Stress/strain curves are shown in figure 1.6.2. (Ref. 1).

Aramids exhibit a very low creep rate, i.e. have good resistance to continued elongation under long term static load. Figure 1.6.3. (Ref. 1) shows Aramid creep rates compared with other tensile yarns. It has been shown by Lafitte and Bunsell (Ref. 5) that creep of Aramids is proportional to the logarithum of the time of stress at any applied stress or temperature. The resistance to creep of Aramids is therefore impressively good in the static load situation.

However when Aramid yarns are bent, flexed, or compressed beyond a certain level they show a fatigue resistance lower than that of polyamide and polyester, which has to be attributed to the high modulus and low elongation of Aramids. Figure 1.6.5. (Ref. 1) shows strength loss of cords when subjected to disc fatigue testing. As can be seen, Aramid performance under flex/compression conditions is poor relative to conventional textile materials, but is still superior to the performance of steel. Woven coated fabrics of Aramid and nylon have been tested on a de Mattia flex tester and it was found that when the Aramid fabric has lost 50% of its strength, the nylon fabric was virtually unaffected (Ref. 6). Figure 1.6.6. (Ref. 6) shows this difference in flex resistance. It can be concluded from these results that the textile constructions which use Aramid yarns should be designed to minimize situations which would cause the yarns to go into a state of compression, and conditions of flexing must be examined in hose, to establish how important flex fatigue is in these applications.

1.6. Physical Properties of Yarns (continued)

The moisture regain of Aramids is similar to that of polyamide at 4 - 5% (Ref. 1) and can cause problems in processing. The moisture regain of polyester is considerably lower than that of Aramid and polyamide at 0.5% and for this reason polyester is the normal, preferred material in moisture sensitive processes e.g. thermoplastic hose extrusion.

2. PROCESSING (TO HOSE) OF ARAMID YARNS

2.1. General

The usual systems for processing polyamide and polyester yarns are basically suitable for processing Aramids. However the low longitudinal elasticity and low single filament decitex of Aramids combined with the relatively weak transverse strength makes them more susceptible to abrasion and "fibrillation" than polyamides and polyester. Because of this it is very important to maintain a high degree of cleanliness and to use guide materials of suitable frictional characteristics. To maintain quality it will be found necessary to use lower processing speeds than those used with polyester and polyamides. In all processing of Aramids it is important to avoid extended exposure to light. It is also desirable to keep humidity constant at 65 $\pm$ 2% (Ref. 7), conditions which are not necessary for the successful processing of polyamide or polyester yarns.

2.2. Twisting/Doubling

Figure 2.2.1. shows the effect of twist on Aramid yarns of differing decitex (Ref. 1). Figure 2.2.2. shows twist factor compared to strength for various decitex Aramid yarns (Ref. 1). As can be seen, care must be taken not to exceed the peak of the graphs in order to achieve maximum make up efficiency. When making single yarns up to the required final ply, the following points should be observed (Ref. 7).

(1) Use minimum number of guides.
(2) Use dull chromium plated yarn guides.
(3) Keep single yarns separated as long as possible.
(4) See that single tensions are low and equal.
(5) Use nylon travellers with steel inserts.
(6) Ensure minimum contact with balloon control rings.
(7) Use 10 - 15 mn/tex balloon tensions.
(8) Minimize exposure to day light - machine creel may require shrouds.

2.2. Twisting/Doubling (continued)

In addition to the above and as previously mentioned the machine should be kept as clean as possible and the machine speed should be kept low enough to minimize abrasion damage. Even when following all the recommended procedures there will still be deposits of broken filaments, fibrils, and spin finish (Ref. 7). It must be noted that provision of constant humidity is a major operation and that if this is not provided it must be expected that a further reduction in processing efficiency will occur. In certain instances it has been found that deposits from Aramids can cause skin irritation and preventitive measures should be taken, e.g. barrier cream for hands. Replacement rates for travellers, guides etc. will be higher than for "conventional" yarn processing, because of the cutting action of the Aramid. Because of the deposits likely to be left by the Aramid it will be necessary to clean the machinery both during Aramid processing and also afterwards preparatory to processing any "standard" material.

2.3. Weaving (Circular)

In the weaving process, weft yarns are fed from a package contained in the shuttle, which passes through the space or "shed" between warp yarns alternatively positioned above and below it. The weft package must be as large as possible since changes of the weft package requires joints in the weft; a potential weakness in the woven structure. This however means that the "shed" must open widely. Because of this need to form a wide "shed" the warp yarns, feeding radially inwards to the circular weaving point or "cup" suffer large, vertical, displacement as they alternate continuously between positions above and below the shuttle.

In a circular loom the mechanism for initiating the shed separation uses either "healds" which are caused mechanically to rise and fall, or a "selector wheel", which is similar to a cog-wheel, but having high and low teeth or grooves which perform the same function as healds. Having initiated shed separation, the shed is opened to accommodate the shuttle by tapering guides attached to the moving shuttle itself. The warp yarns entering the loom must also be located circumferentially by passing through individual gaps in the "comb", and in reciprocating in the vertical plane, they suffer continual transverse abrasion against the sides of the comb. Thus, all looms, and particularly circular looms, designed for conventional polyester and nylon yarn weaving, subject the yarns to considerable flexing and abrasion against surfaces of the equipment. These are two of the properties where Aramid yarns are inferior to conventional yarns, and it remains to be seen how serious these disadvantages are in practice.

2.3. Weaving (Circular) continued.

Healds and combs should be of stainless steel, as should selector wheels if that method of "shedding" is employed. Guides should again be dull chrome and should be kept to a minimum.

The single most important consideration in weaving Aramids is the equalisation of warp lengths in the woven fabric.

In woven fabric, the warp and weft yarns pass over and under one another in a set pattern depending upon the weave design. This causes the yarns to be wavy or crimped rather than straight. If a hose is subjected to pure tensile loading, the warp crimp is reduced and the weft crimp increased. Further loading completely removes the warp crimp and also causes extension of the warp yarns themselves. Breakage of the yarns occurs when they reach their maximum extension i.e. extension at break. The hoses under discussion contain several hundred individual warp yarns. If tension is applied to a hose, warps will begin to break when the excess length due to crimp is removed and the yarn extension to break is reached, i.e. break point is equal to warp crimp plus yarns final extension. Clearly high hose tensile is only achieved if all the warps reach their breaking extension at the same time. With conventional nylon and polyester yarns, having some 12 - 25% extension at break, this is not too serious a problem, since variations in the warp crimp or warp length (length of yarn in unit length of hose) are small compared with yarn extensibility.

However Aramid yarns break at only 3 - 4% extension. In consequence variations in length of all the warps in the hose must be much less, in order to use the additional strength of the yarns through good strength conversion from yarn to hose. In practice, this means controlling input warp tensions and loom geometry much more accurately than normal and modifications to the loom may be required to achieve satisfactory yarn to hose strength conversion efficiency using our present looms.

Guides, selector wheels etc. will require more frequent replacement because of the cutting action of Aramids. Because of the deposition of dust and broken filaments encountered during Aramid weaving it may prove necessary to install a dust extraction system on the loom. Any accumulations of Aramid dust or fluff will cause mis-weaves and poor quality jacket to be produced. Again thorough cleaning will be needed before weaving standard yarns on a loom previously used for Aramid weaving. It will probably be necessary to reduce the weaving speed by up to 30% in order to optimise weaving performance. Again exposure to day light should be kept to a minimum and this may mean fitting a shroud around the loom creel.

2.4. Coating/Extrusion

Because of Aramids' poor resistance to day light it is necessary to apply an outer covering or coating to the woven jacket for U.V. protection purposes. Obviously this outer coating/covering will also resist abrasion and protect the woven jacket reinforcement from damage.

The relatively high moisture regain of Aramid causes problems in thermoplastic extrusion, the moisture liberated from the Aramid because of the high temperatures in the extrusion head causing blisters. It is therefore very important to dry the woven jacket thoroughly and to keep it dry until the cover is applied. Experience has shown that conventional drying equipment as used for polyester/thermoplastic hoses is insufficient for Aramid/thermoplastic hoses. Chemical drying would seem to be required - this again is a radical departure from normal operating practice. Rubber extrusion of Aramid jacket does not present the same moisture problems, however rubber may not have the required properties, e.g. potable water clearance, fuel resistance. There is also a major objection to the use of rubber with Aramid in that vulcanisation of the rubber is necessary and it has been shown that the vulcanisation of Aramid reinforced rubber coated hose can cause up to 50% strength loss in the Aramid (Ref. 8). This strength loss is at present unexplained, but it is not merely a thermal effect, as Aramid reinforced thermoplastic hoses do not show this dramatic strength loss.

Coating of Aramid jacket may be the easiest route, but this will entail the use of a separate lining. There will be difficulties adhering both the coating and the lining to the Aramid as Aramids exhibit very little affinity for currently available adhesives. On an extruded hose pillar adhesion gives adequate levels of adhesion, i.e. cover and lining are unified through the holes in the jacket weave, this is not the case with a coated outer and a separate inner lining.

3. HOSE PROPERTIES

3.1. General

Although the high modulus and tensile of Aramid yarn provides great opportunities for advancement of hose performance it also imposes constraints on methods of manufacture and types of end use. In theory it is possible to manufacture very high tensile, high burst extruded hoses using Aramid reinforcement. However it must be borne in mind that Aramid performance in all hose making processes has never been fully monitored and it is quite likely that the make up efficiency of the Aramid at each stage of manufacture will be lower than that of polyester. It is also likely that this make up efficiency will be lower when producing all Aramid woven jackets than that found with Aramid in one direction in the

3.1. General (continued)

jacket and polyester in the other. Aramid to Aramid contact has been found to produce more damage than Aramid to polyester contact (Ref. 7).

3.2. Properties of Aramid Warp, Polyester Weft Hoses.

The use of Aramid warp yarn should make possible the production of very high tensile, low elongation hoses. If all the attendant processing problems can be overcome it should be possible to simply replace polyester in a "normal" construction with the same total weight of Aramid and achieve ca 250% increase in tensile properties. This assumes no above normal losses caused by weaving probelms. In practice, as explained earlier, it will be very difficult to achieve this level of increase due to difficulties in equalising warp crimp. Using polyester weft will limit the short length burst pressure to relatively low levels ca 1000 psi for 6" I.D. hose, because of the very high packing densities required to exceed these levels. The extension under load of an Aramid warped hose could be expected to be only ca 25% of the value obtained from a polyester warped hose. The uses to which an Aramid warped hose could be put would need to be carefully defined in view of the very poor flex performance of Aramid yarns. The ideal use for such a hose would be in a permanently tensioned, zero movement application. The lower the amount of flexing the hose is asked to stand, the longer will be its useful life.

3.3. Properties of Aramid Warp and Weft Hoses.

The use of an all Aramid construction should make possible the production of a low extension, low swell, high tensile, high burst hose. Again, as in 3.2., if all the attendant problems can be overcome, then a 250% increase in burst and tensile over polyester constructions could be possible. The low elongation of Aramid yarn gives an added bonus from the point of view of burst, in that the reduced swell of the hose gives a higher burst for a given amount of weft, i.e. burst is proportional to diameter. The reduced swell does however mean that there will be a reduction in throughput of the hose, i.e. the Aramid hose will have a smaller internal diameter than a polyester hose at the same pressure. Again as in 3.2. the hose application must be carefully chosen because of the poor flex performance of Aramid. Ideally an all Aramid hose should be used in a constant pressure, constant load situation or in an application where inflation/deflation and bending/flexing is at a minimum.

3.3. Properties of Aramid Warp and Weft Hoses.

Probably the most important weakness of Aramids is their weakness in compression, which gives rise to splitting of the individual filaments into fibrils. Two aspects are of direct concern to lay flat hose:-

(1) In the crease of the lay flat hose edge the hose wall is bent into a semi-circle of low diameter. Having finite thickness, the inner side of the wall is in compression.

(2) When the hose is inflated to the working pressure of 1/3 burst pressure, the warp extension is about 1/3 of the break extension of 2%, i.e. 2/3%. If the hose is bent into a circular loop, again, the longitudinal extension of warps on the outside of the loop is increased, but that of the warps on the inside of the loop is reduced. If the radius of the loop is x feet on the neutral axis of the loop, the radius of the external face is x + 0.25 ft. for a 6" diameter hose and that of the inner surface is x - 0.25 ft.

Extension of the inner loop face is zero when

$$\frac{x + 0.25}{x - 0.25} = \frac{100 + 2/3}{100}$$

Therefore x = 75.3 feet.

Whilst this calculation is crude, it does demonstrate that an inflated Aramid warped hose is not easy to bend into a tight loop, and when forced into a loop, even of moderate radius, the inner warps soon go into the state of compression, which is undesirable for Aramids. With more extensible yarn, tighter loops are obviously possible without forcing warp yarns into compression.

Any work done with Aramid constructions must therefore include test methods in which inflated hose is flexed, to establish how severe is the problem.

4. GENERAL COMMENTS AND SUMMARY

Whilst Aramid yarns offer 2 - 2.5 times the strength of nylon and polyester yarns and could thus lead-to greatly enhanced hose performance in tensile and hydraulic characteristics, some of their other mechanical properties present problems in conversion to lay flat hoses and may present problems in obtaining good field performances of the hoses themselves.

4. GENERAL COMMENTS AND SUMMARY (continued)

Two inherent problems stem from the low extension at break, and the weak compressive strength of the yarns. Low extension at break requires special tension and feed rate control at weaving, to enable the tensile load on a hose to be shared equally among the longitudinal warps; a necessity in obtaining good conversion of total warp yarn strength to longitudinal hose strength. Low extensibility also leads to rigid hoses which, when looped in the inflated conditions can soon force some of the warp yarns into compression, which can cause severe deterioration in mechanical properties.

This programme has served to identify the main problems, and to cause us to examine all aspects of hose manufacture with a view to minimizing the problems envisaged, by considering optimum hose design, yarn doubling and weaving equipment and conditions, hose testing methods, etc.

It must be emphasised however that use of Aramids in these applications has received little previous examination and present knowledge would indicate that even modern circular looms, designed to weave conventional yarns are not well suited for the projected development and major modifications may well be required.

Because of these factors, and of the very high unit cost of Aramids we have chosen to do the early evaluations on 4" hose to provide the experience and understanding for later scale up to 6" hoses.

5. LIST OF FIGURES

6\.

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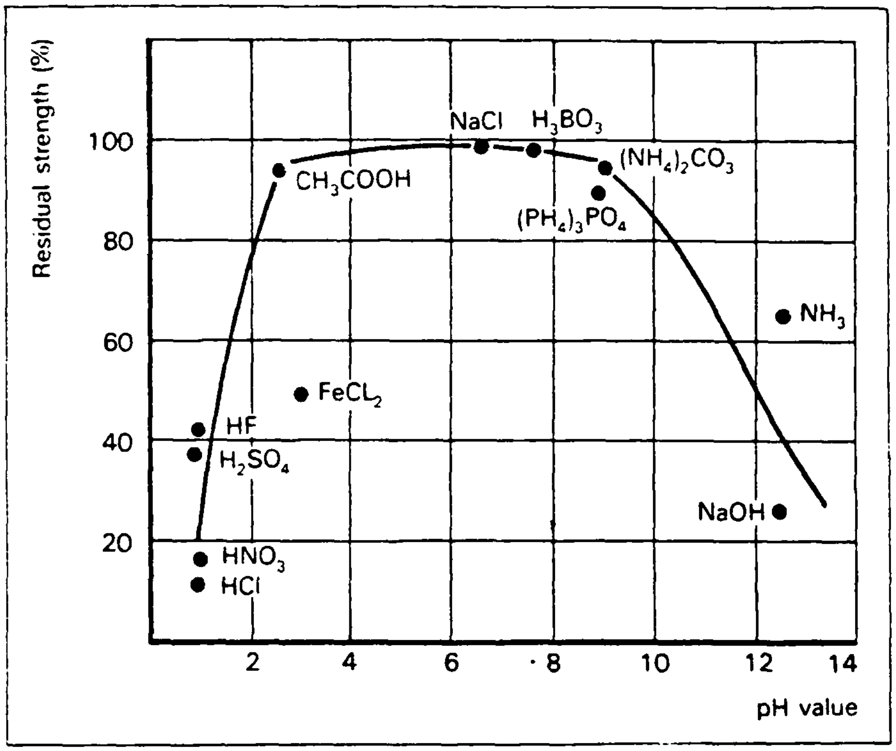
Fig. 1.4.1



Twaron resistance to chemical attack, exposure time: 3 months, room temperature.

Fig 1.4.2

Mediums at room temperature	Days of storage			
	12	40	120	300
Gasoline	100	103	102	98
Toluene	103	104	104	100
Trichloroethylene	103	104	100	103
Methanol	105	105	107	102
Diglycol	101	102	101	101
Formalina 3%	101	103	101	103
Turpentine	99	97	92	–
Heating oil	98	97	95	–
Cooling liquid	99	97	97	–
Acetic ester	99	98	96	–
Formalina 40%	98	97	95	–

Relative residual maximum tensile strenght of Twaron filament yarn after storage in various organic mediums at room temperature.

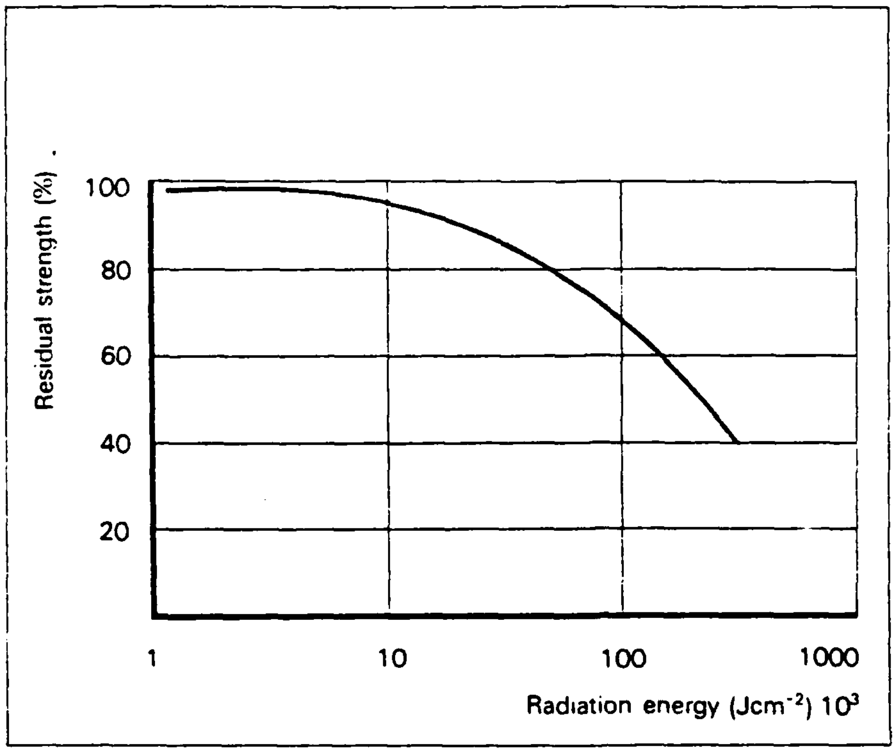
Fig 1.4.3

Mediums at room temperature	Days of storage			
	12	40	120	300
Hydrofluoric acid 10%	85	70	52	–
Boric acid 0.1 n	104	104	104	103
Nitric acid 10%	28	23	16	14
Hydrochloric acid 10%	33	25	16	12
Sulphuric acid 10%	87	85	49	38
Acetic acid 10%	100	102	100	94
Caustic soda solution 10%	59	38	27	25*
Ammonia 10%	101	95	79	64
Aniline, satured solution in H_2SO	102	101	101	–
Common salt 5%	98	98	98	–
Sodium sulphate 10%	101	104	102	100
Ammonium carbonate 10%	100	104	95	96
Ammonium phosphate 10%	100	101	98	93
Iron perchloride 10%	98	89	69	47

*After 375 days.

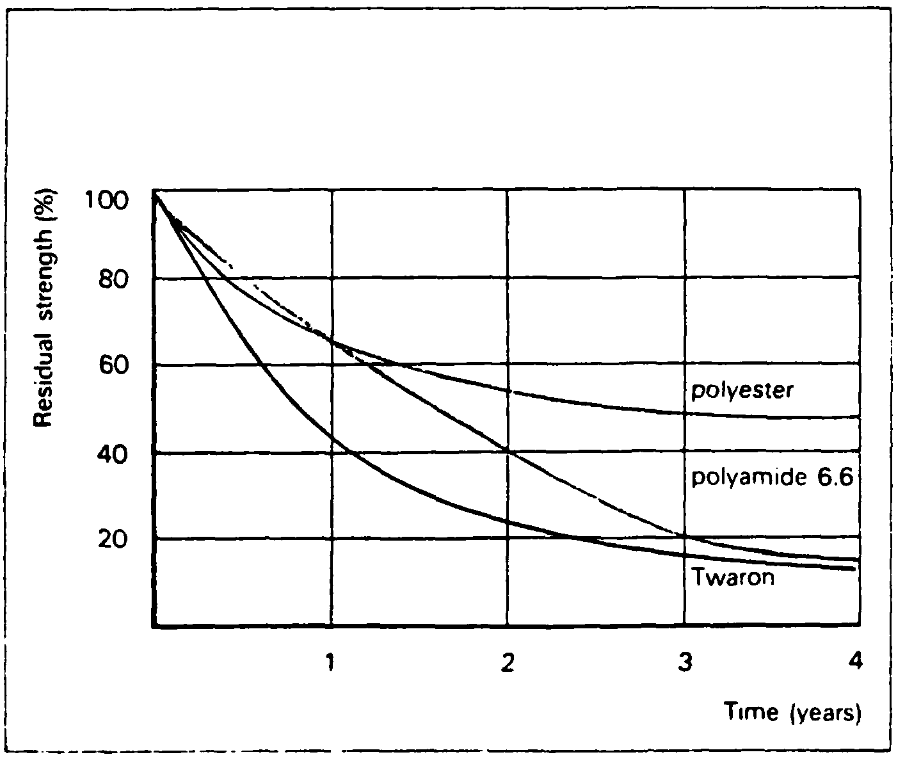
Relative residual maximum tensile strength of Twaron filament yarn after storage in various inorganic mediums at room temperature.

Fig 1.4.4



Influence of the radiation energy during outdoor exposure on the residual strength of Twaron.

Fig 1.4.5



Influence of outdoor exposure on the strength of Twaron compared to polyester and polyamide.

Fig 1.5.1

THE EFFECT OF TEMPERATURE ON THE TENSILE STRENGTH OF KEVLAR

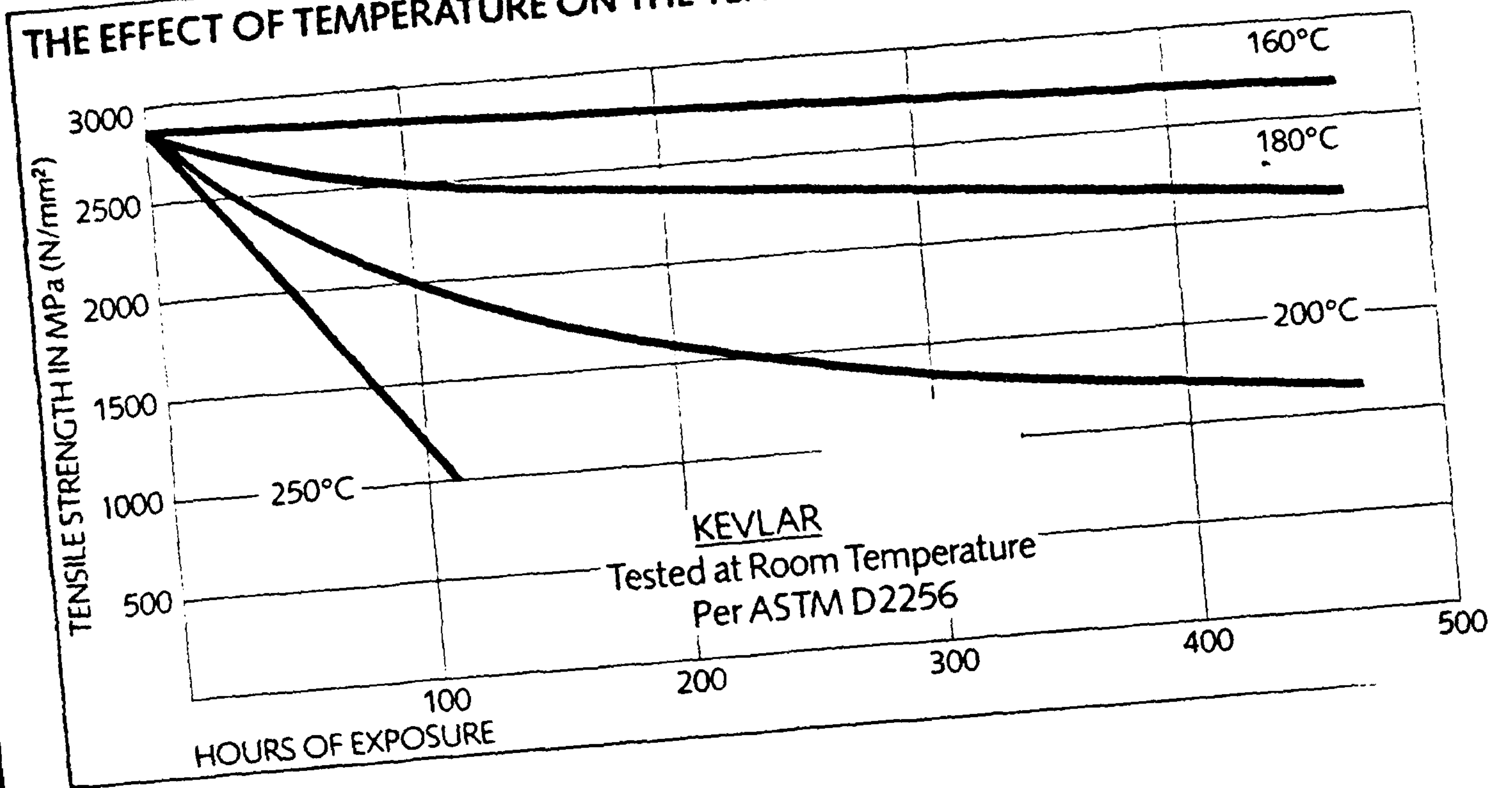


Fig 1.6.1

Typical Tensile Properties

	"Kevlar" Aramid	Steel (stranded)	Nylon	Polyester	R
Tenacity (cN/Tex)	190	30-35	86	82	
Tenacity (N/mm^2)	2760	2400-2800	1000	1150	
Modulus (N/tex)	44	18-25	4.6	9.7	
Elongation at Break (%)	4	2.0	17	14.5	
Density (g/cc)	1.44	7.85	1.14	1.38	

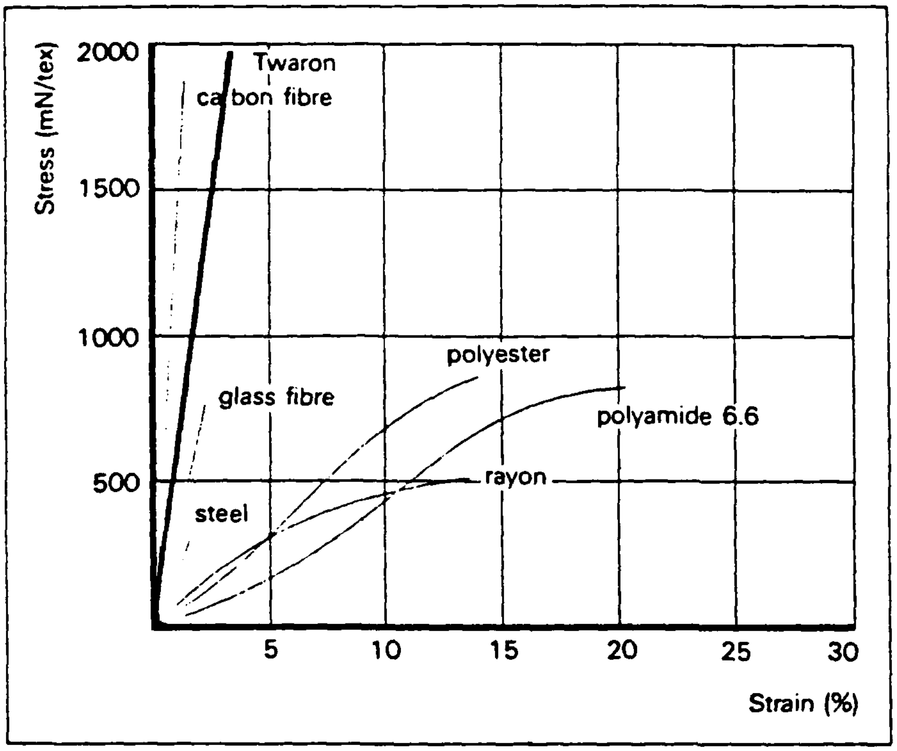
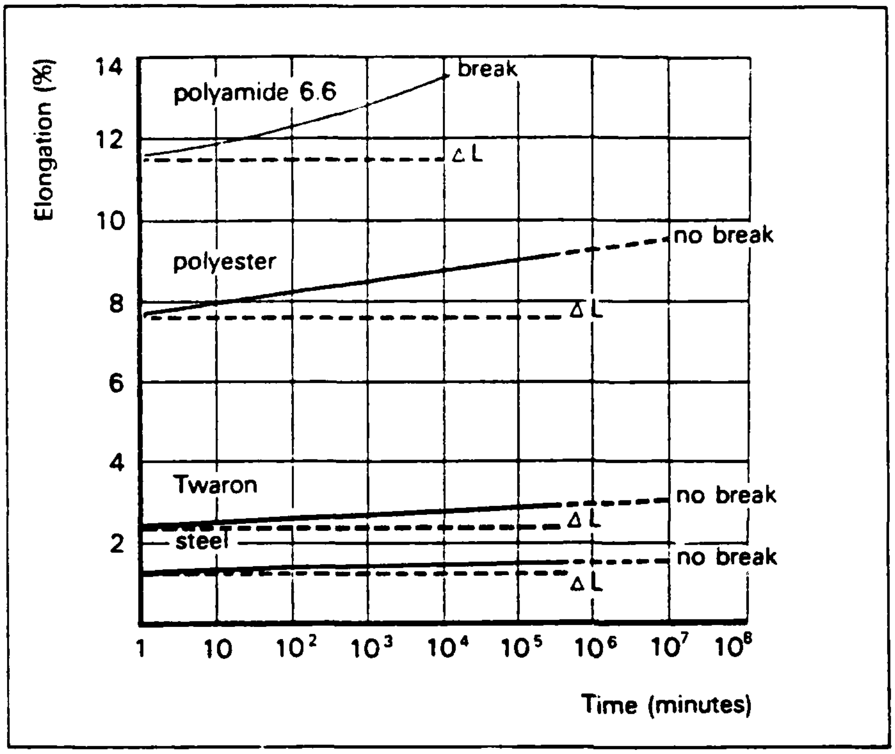


Fig 1.6.2

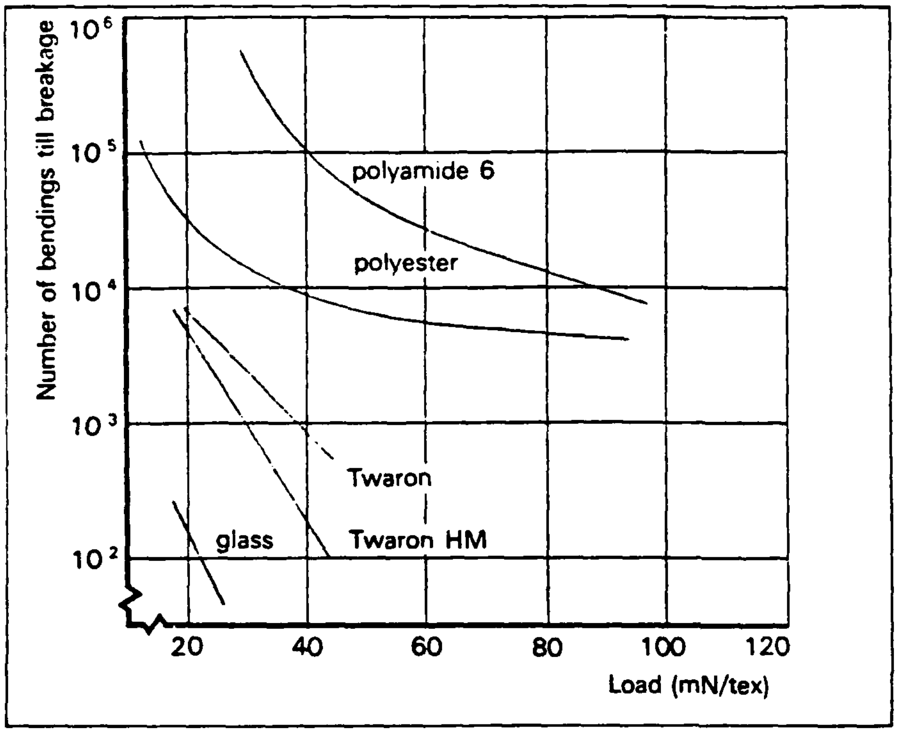
Stress-strain relationship of industrial yarns.

Fig 1.6.3.



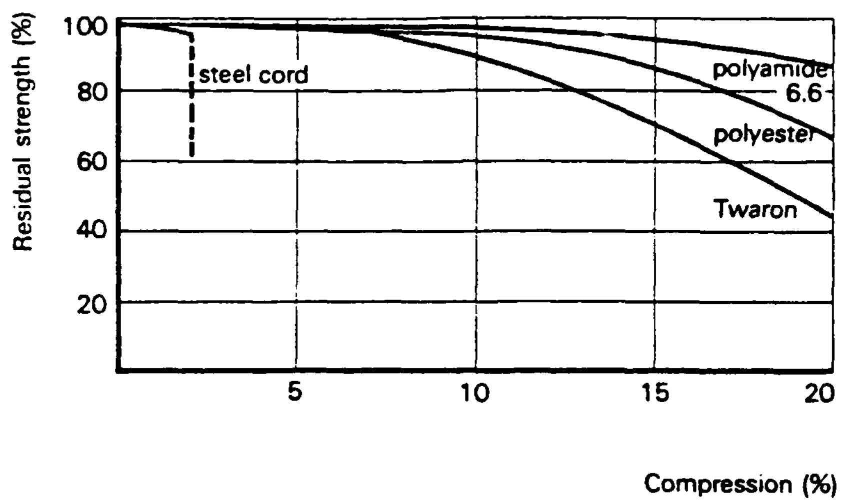
Creep of Twaron cords under 60% of the breaking load, compared with polyamide 6.6, polyester and steel cords at room temperature.
Over a period of about a year Twaron cord grows only about 0.2%, steel 0.05% and polyester about 1.3%. Polyamide 6.6 cords break after two weeks, the creep elongation being 2.1%.

Fig 1. 6. 4.



Bending fatigue of Twaron filaments compared with that of other materials.

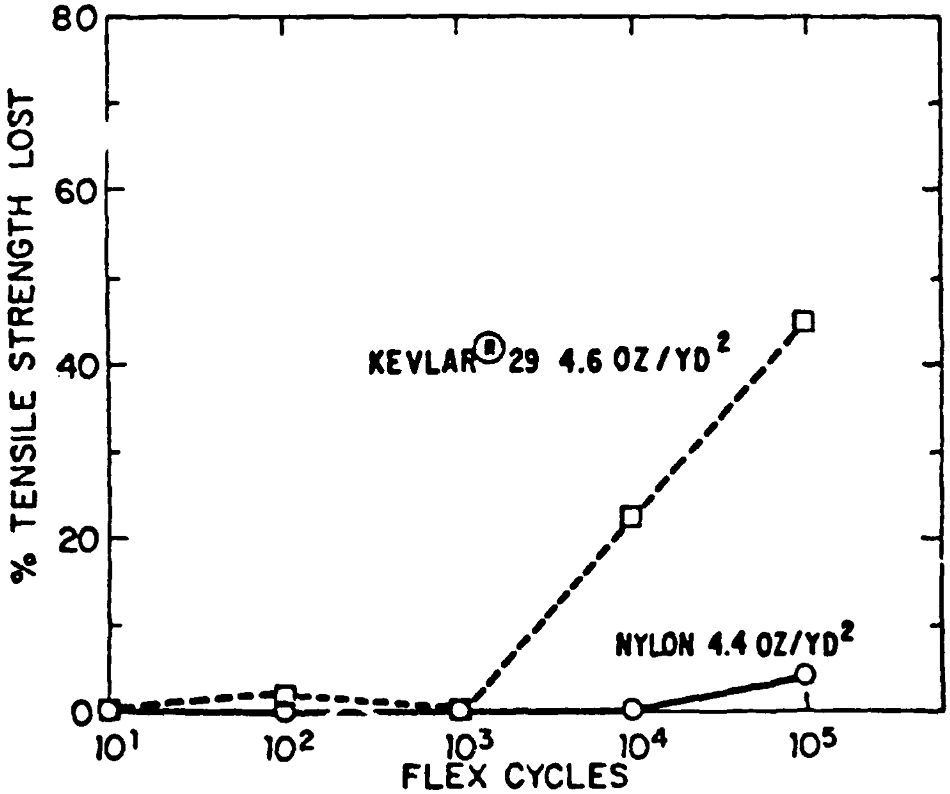
Fig 1.6.5



Residual strength (%) after disc fatigue testing of steel, polyamide, polyester and Twaron tire cords.

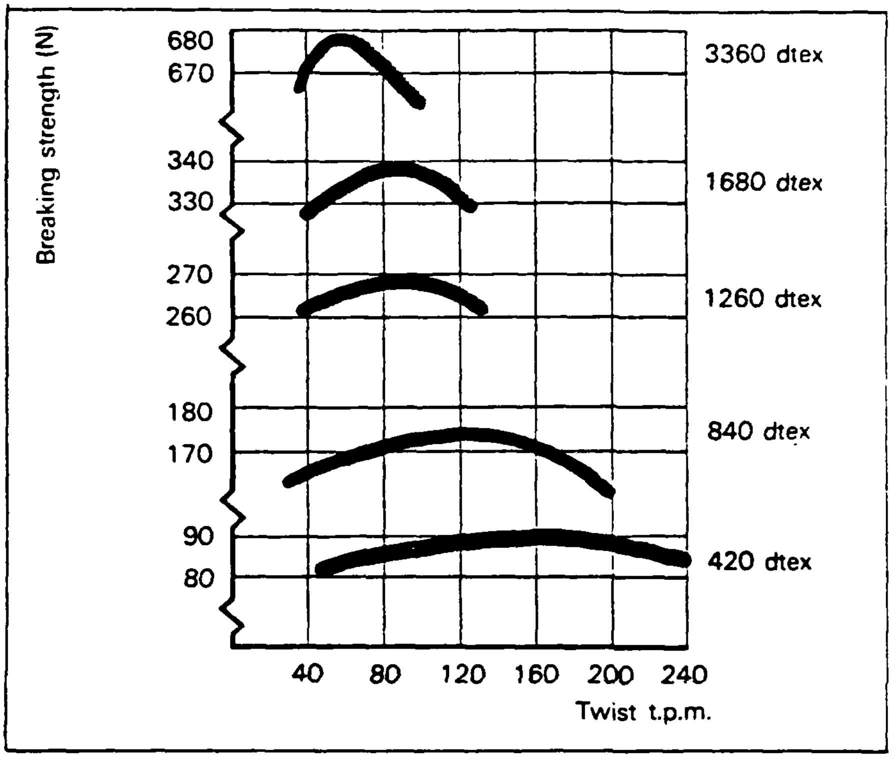
Fig. 1.6.6.

Marilyn Wardle



Flex fatigue of vinyl-coated fabrics made from Kevlar® Aramid and Nylon – 5 oz/yd² weight class.

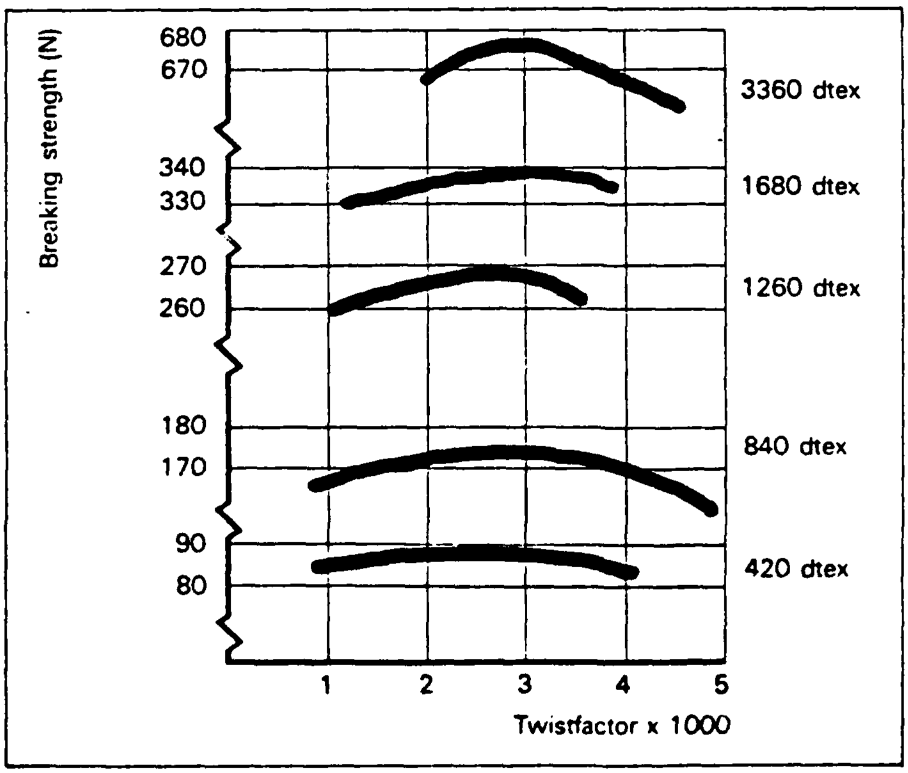
Yarn twists, optimal twist factor



Twaron filament yarns are supplied with zero twist. For reaching maximum strength a certain twist has to be applied.

Fig 2.2.1

Twaron - Type 1000. Influence of twist level in single yarns on breaking strength.



If the twist is expressed in a twis factor which is a measure of the twist angle, it is found that the strength maxima for all dtexs ar in between 2400 and 3400.

Twist factor $T = n\sqrt{t/\rho}$
n = twist in turns/metre
t = count in dtex
ρ = density in g/cm³

Fig 2.2.2

Twaron - Type 1000. Influence of twist factor of single yarns on breaking strength.

Appendix B

MANUFACTURING TRIALS WITH ARAMID YARNS TO PRODUCE HIGH PERFORMANCE LIGHTWEIGHT COLLAPSIBLE PIPELINES

MANUFACTURING TRIALS WITH ARAMID YARNS

TO PRODUCE HIGH PERFORMANCE LIGHTWEIGHT

COLLAPSIBLE PIPELINES

Prepared For:

Naval Civil Engineering Laboratory
Port Hueneme, California

Under Contract:

N-62474-84-C-3144
Phase II, Part II, Item 4.3.2

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High Strength Collapsible Pipeline
US Navy Development Contract

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High Strength Collapsible Pipeline
US Navy Development Contract

SUMMARY

The objective of the project was to prove that by using high strength aramid yarns it would be possible to produce 6 inch diameter collapsible pipelines with a tensile strength of 100,000 lbs. Two bursting pressure requirements were stipulated, one with a polyester weft at 750 psi and the other with an aramid weft at 1800 psi.

For economy the weaving trials were carried out on pipelines of 4 inch diameter and the results scaled to arrive at values obtainable with an equivalent hose of 6 inch diameter.

In general terms the trials went well and two sample lengths of the hoses required were produced. The burst performances of the hoses were above the specification stated but tensile strength was only about 65% of the value required.

However with the information gained from this project we believe it would now be possible for us to produce trial lengths of 6 inch diameter hose which would meet or be very close to the burst and tensile performance required.

1. INTRODUCTION

This report gives details of manufacturing trials using aramid yarns for the production of high performance, tubular woven, collapsible pipelines suitable for carrying fuel. A feasibility study has already been issued as part of this contract which gives details of the properties of aramid yarns and their possible use for this type of manufacturing process.

It was considered that the most economic approach would be to produce 4" diameter pipelines in order to establish the practicability of attempting large diameter production such as 6". Most of the work carried out has been concerned with tubular weaving as a first essential in the fabrication of covered pipeline. In order to produce small samples for evaluation it was necessary to produce linings and covers for the pipeline using different techniques to our normal manufacturing process. Further work would be required if we were to establish the use of aramid yarns in the complete pipeline production process which includes yarn preparation, weaving, lining and covering.

2. WOVEN JACKET MANUFACTURE

2.1. Jacket Design

Two different jackets were required, namely (a) high pressure (HP) and (b) very high pressure (VHP). Both were to give nominal 4" finished internal diameter, but the constructions were to be such that they would demonstrate the feasability of 6" diameter HP and VHP products. The performance targets for these 6" diameter hoses were quoted as :-

HP 750 psi short length burst pressure (SLBP)
100,000 lbs tensile (actual).

VHP 1800 psi SLBP
100,000 lbs tensile (actual).

To scale down to 4" diameter and yet keep the same degree of cover, ie. for the 4" jacket to look identical to the 6" jacket except for size, the 4" hose properties would be :-

(a) HP

$$\frac{750}{4} \times 6 = 1125 \text{ psi SLBP}$$

$$\frac{100{,}000}{6\pi} \times 4\pi = 66{,}666 \text{ lbs tensile}$$

(b) VHP

$$\frac{1800}{4} \times 6 = 2700 \text{ PSI SLBP}$$

$$\frac{100{,}000}{6\pi} \times 4\pi = 66{,}666 \text{ lbs tensile}$$

Both jackets were therefore designed to have a tensile end break of 66,666 lbs and short length burst pressures of 1125 psi and 2700 psi for the HP and VHP variant respectively. It was decided that the VHP variant needed to employ aramid warp and weft to reach the targets set, whilst the HP variant needed aramid warp also, but only standard polyester weft. Both constructions were designed to be 'open' enough to allow possible thermoplastic extrusion, ie. jacket to have sufficient space between warp and weft to allow polymer through to form a lining. The weave pattern was chosen to contribute both to 'openness' of the jacket and to flexibility and handle.

2.2. Yarn Make-Up

2.2.1. Aramid Warp Yarns

The yarn purchased was a 1680 decitex twistless aramid. The design for both types of jacket required the yarns to be combined to produce a 5 ply construction for the warp. This was performed using conventional ring doubling machines fitted with special steel insert travellers.

Normal production speeds were used and there were no mechanical or other technical problems apparent at this stage of the process. The dust and 'fly' generated was greater than normal yarns but for this small trial no special precautions were needed to counteract this.

The finished yarn appeared quite satisfactory when examined visually but it was also tested for tensile strength :-

Theoretical strength for 5 ply yarn	-	165 DaN (Deca Newtons)
Actual strength	-	112 DaN
Make-up efficiency	-	68%.

Any process handling yarns causes some loss of strength due to the yarns wearing and being otherwise damaged. Aramids are known to be more susceptiable to such damage than other types of yarn but a make-up efficiency of 68% is extremely low. It seems certain that differences in the length of the individual yarns made up to the 5 ply construction contributed to the poor tensile performance. With high modulus yarns the strength of each ply must be exactly matched to achieve even load sharing and thus maximum performance.

Obviously in the preparation of the warp yarns - the process was not entirely suited to the nature of the aramids.

2.2.2. Aramid Weft Yarns

Several alternative methods of combining plies to make up the weft yarns were tried in order to overcome the make-up efficiency problems experienced when producing warps. Weft yarns are rewound onto small shuttle packages unlike warp yarns which are wound directly onto a large number of bobbins to make up the warp creel. This made it practical to make modifications to one macnine and use this for all weft production.

The final weft yarn produced combined 4 plies of 1680 decitex aramid and gave the following test results :- (1500 denier)

Theoretical strength	-	*528 DaN*
Actual strength	-	*464 DaN*
Make-up efficiency	-	*88%.*

This was considered to be a most satisfactory result and is obviously a significant improvement on the results obtained with the warp yarns.

Again a certain amount of dust generation was experienced during yarn processing.

2.2.3. Polyester Weft Yarns

The polyester yarns used were 1100 decitex and the jacket design required a 6 ply weft yarn to be produced. In order to give a direct comparison it was decided to produce the polyester weft using the same process as that employed for the aramid weft. Strength tests gave the following results :-

Theoretical strength	-	*199 DaN*
Actual strength	-	*182 DaN*
Make-up efficiency	-	*91%.*

This is a satisfactory result but is not significantly different to the results expected using our normal processes for the production of polyester yarns. Obviously the low modulus and higher extensibility of polyester makes it much more tolerant to variations in the make-up process.

2.3. *Circular Weaving*

All practical steps were taken to equalize warp tension around the loom without major loom redesign. Both jacket constructions were woven using conventional mild steel loom parts since it was not feasible to replace these with more ideal materials for a short test weave such as this trial.

No special problems were encountered during weaving. Dust generation was greater than with conventional yarns but fortunately with only a relatively short length of jacket to be woven this did not give rise to weaving faults. With full scale production improved dust extraction would however be essential.

After completion of weaving, examination of the loom revealed excessive wear on certain mild steel components used to guide and tension the yarns. It was necessary to replace these components before returning the loom to normal production.

3. *HOSE LINING*

3.1. *Conventional Lining Trials*

With conventional products the hose lining and cover are applied in a single process which encapsulates the woven jacket in the selected elastomer. Different die components and running conditions are necessary for the many types of jacket processed and optimum conditions are only fully established after a number of extrusion trials where several hundred feet of jacket may be used up.

Only short lengths of the trials jackets were available and it was not considered an acceptable risk to use the extrusion process in a single attempt to obtain finished products. An additional factor was the known requirement for special jacket drying equipment when processing aramid yarns.

Alternative more simple methods exist for providing pipe linings which involve the pre-extrusion of a polymer tube which is coated with a suitable adhesive and then inserted into the jacket. In order to evaluate the jacket performance for burst and tensile it was considered that linings produced in this way would be acceptable. An advantage of this approach is that tests can be made on very short lengths of 3 ft. or so.

Attempts were made to provide a rubber lining and adhesive system using materials available from other types of hose which we produce. Under pressure testing these linings failed and gave rise to small pinhole leaks.

The jacket design used is an open weave with coarse yarns which is necessary on the 'one shot' extrusion process used to provide cover and lining. This type of construction also provides a more flexible end product. Examination of the failed linings showed that under pressure the rubber linings were being forced into the interstices of the weave leading to distortion and failure.

Further trials were carried out using excessive quantities of adhesive to block the jacket but these also failed. Alternative thermoplastic materials were also tried in place of rubber but again no reliable lining was developed using this approach.

3.2. *Reinforced Linings*

In order to overcome the lining problem outlined above it was decided to use a polymer lining which was itself fabric reinforced. Effectively this provides a hose within a hose and the technique has been used for many years on certain of our other products. By using a fine weave fabric to support the polymer lining this was expected to prevent leaks developing under pressure.

A special fine weave jacket was produced in a size to match the internal diameter of the high tensile test jackets. The inner jacket was circular woven using polyester yarns and was designed to have higher extension and swell characteristics than the high tensile jackets. This ensures that the main jacket always takes the load and supports the liner.

The inner jacket was itself lined with a .025" thick extrusion of 'Hytrel' thermoplastic elastomer. 'Hytrel' is a trademark of the DuPont company and details of the properties of 'Hytrel' are attached.

It was convenient to use 'Hytrel' because the extrusion plant required for this process was already charged with the 'Hytrel' polymer for the production of other products. Although 'Hytrel' is suitable for the purposes of this trial it would not necessarily be our choice of polymer for full production runs using the 'one shot' extrusion process.

It was necessary to provide an adhesive to secure the lined inner jacket to the high tensile jacket. Several systems were investigated with varying success. The final choice involved wrapping a .004" film of hot melt polyurethane around the inner jacket and inserting this into the high tensile jacket. The assembly was then connected to a steam supply and subjected to internal steam pressure in order to activate the adhesive and thus secure the reinforced lining to the main jacket.

A possible problem arising from the use of a reinforced lining was that the total thickness of the pipeline would be increased and this would produce a stiff product which would be difficult to flatten. In the event it was found that the pipeline was not unduly stiff.

4. COVER PROCESSING

It would be possible to test the pipeline without providing a protective outer cover. However aramid yarns are known to degrade in sunlight and filament excessively when abraded and a suitable cover would obviously help these problems.

Direct extrusion of a cover was not possible as explained in section 3.1. and several alternative systems were considered. Some tests were carried out using water based acrylic coating and also PVC plastisols. These were unsatisfactory for adhesion strength and the thickness of coating which could be built up.

Solvent based coating systems could overcome these problems but we did not have facilities for the safe handling of such materials on the scale required. It was known that certain companies have equipment for coating steel pipes and other structures with polyurethane protective coatings. By inflating the pipeline to make it effectively rigid it was hoped that it could be coated in asimilar manner to steel pipes.

Contact was made with a company capable of doing this type of work and after some initial trials it was agreed to submit the 20 ft. sample lengths for covering.

A two pack solvent based polyurethane cover was applied using airless spray with two coats to build up sufficient thickness. Grey pigmentation was used. Cover thickness varied from .040" to .075" because of the difficulties experienced in building up a uniform cover on a circular profile the spray technique.

The samples were allowed to air dry for 5 days in order to remove the bulk of the solvent and allow full development of the polymer properties.

It is not considered that this method of covering would be a practical system for use in a full scale production process. Only short lengths can be processed and the process is expensive. However the samples produced in this way were very similar in appearance and properties to hoses produced on our normal extrusion equipment and in this manner suited the purposes of the trial very well.

5. *FINISHING*

The pipelines were hand branded with a standard white solvent based branding ink. Sample 20 ft. lengths of the two pipeline constructions were coiled for dispatch. Coiling presented no problems and both pipelines flattened and coiled easily.

6. FINAL TESTING

A list of test results can be found in Appendix I.

Note that the finished diameter of both hoses was 4.5" and this affects the bursting pressure required as models for 6" hose as given in section 2.1.

Tensile performance is not affected since the same number of warp ends would be involved whatever final weave diameter was obtained.

6.1. Pressure Testing
HP Pipeline

The short length burst was 1550 psi.

This value can be corrected to the equivalent burst for a 4" diameter hose

$$\therefore \text{Burst at } 4'' = 1550 \times \frac{4.5}{4} = 1743 \text{ psi}$$

As a model for a 6" hose this becomes a theoretical

$$1743 \times \frac{4}{6} = 1162 \text{ psi}$$

This comfortably exceeds the 750 psi required for a 6" hose with a polyester weft.

The weft yarn tensile recorded in section 2.2.3. can be calculated to provide a 4" pipeline of this construction with a theoretical burst of 2181 psi. Comparing this with the derived burst of 1743 gives a weave efficiency of about 80%. For a circular woven product this is a high weave efficiency.

6.2. Pressure Testing
VHP Pipeline

With the VHP pipeline pressure was raised to 2400 psi, which is the maximum available on our test rig, but the hose did not burst. Taking this value and correcting the diameter from 4½" to 4" gives :-

$$2400 \times \frac{4.5}{4} = 2700 \text{ psi}$$

The theoretical burst for a 6" hose is therefore :-

$$2700 \times \frac{4}{6} = 1800 \text{ psi.}$$

This matches the burst performance required but since it was not possible to burst the hose the full performance is unknown. If we assume a weave efficiency of 70% compared to the 60% achieved with the HP pipeline, a possible indication of burst can be calculated from the known weft strength. For a 4" pipeline this would give an estimated burst pressure of 3750 psi which is equivalent to 2500 psi for a 6" pipeline. In any event it is shown that we exceed the required burst specification.

6.3. Tensile Testing

Both pipelines have identical warp construction and should therefore have the same tensile strength. From the measured warp strengths a theoretical tensile for both products would be 73015 lbs. Actual tensiles achieved were :-

HP	42,372 lbs.
VHP	44,092 lbs.

This gives warp efficiencies of :-

HP	58%
VHP	60%

For 6" pipelines these results would be equivalent to :-

HP	63,558 lbs.
VHP	66,138 lbs.

These results are well below the 100,000 lbs. required in the specification for a 6" pipeline.

With all of the tests for tensile strength the pipelines failed at the couplings despite using a special type of coupling designed to avoid this problem. Coupling damage may have contributed to the low tensile performance.

Other factors contributing to poor tensile performance are discussed later.

6.4. Other Tests

It is also planned to carry out some flex cycling tests to examine any effect this may have on performance. This type of test may give some indication of service life but it is is not intended to model field conditions in order to make accurate predictions.

Any full study of expected working life would require a much more accurate definition of the conditions operating in use by the US Navy. Indeed it would seem most practicable to fully examine this question when production 6" pipelines are available for evaluation in the field. Static pressure tests using water in place of fuel might be considered as a suitable method of evaluation.

7. DISCUSSION OF RESULTS

Tensile and Burst

Although the test objectives were not all achieved, the work has indicated that aramid yarns can be processed on our normal weaving equipment. Three factors may have contributed to the poor tensile results:-

(1) Poor warp make-up efficiency.

(2) Coupling damage.

(3) Absence of a lining and cover system which encapsulates the jacket yarns.

An encapsulating cover/lining helps to equalize yarn tensions and stabilizes the weave and would help to protect yarns from coupling damage. The make-up efficiency of the aramid warp yarns was only 68% whereas the aramid weft made up using different processing showed an efficiency of 88%. Making up warp yarns with the same process used for weft yarns should raise the tensile to around 55,000 lbs. equivalent to 82,500 lbs. on a 6" pipeline.

If fact, such a change should also give a significant improvement on the warp weave efficiency and with some adjustments to jacket design, it appears that jackets with the required performance could be produced.

8. POSSIBLE FUTURE WORK

This report has determined that technically a 6" diameter high strength hose constructed of aramid jacket may be possible. No technical reasons were uncovered which suggest stopping the project.

The next stage would be to produce working samples of 6" hose. Work should center around only one type of hose with the VHP all aramid hose being the choice. This hose would allow full evaluation of the use of aramid in the jacket.

Couplings must also be designed in conjunction with the hose. Meaningful test of burst and tensile can only be accomplished with good couplings since most hose failures tend to occur at the coupling.

APPENDIX I : TEST RESULTS

PROPERTY	H.P. HOSE	V.H.P. HOSE
S.L.B.P.	1550 p.s.i.	2400 p.s.i.*
Tensile	42,372 lbs.	44,092 lbs.
Finished I.D.	4½"	4½"
Finished Weight	1.14 lbs./ft.	1.21 lbs./ft.
Total Thickness	0.20"	0.22"
Cover Adhesion	Not possible to test	Not possible to test
Lining Adhesion	3-4 lbs./1" strip	2-3 lbs./1" strip

0-100 p.s.i. swell	2.48%	2.05%
0-200 " "	4.15%	2.46%
0-300 " "	4.56%	2.46%
0-400 " "	5.39%	2.87%
0-500 " "	7.05%	2.87%
0-600 " "	9.13%	2.87%
0-700 " "	)	3.28%
0-800 " "	) Unsafe to test	3.28%
0-900 " "	) at these pressures	3.28%
0-1000 " "	)	3.69%

0-100 p.s.i. extension	0.75%	1.29%
0-200 " "	1.20%	2.28%
0-300 " "	1.85%	3.17%
0-400 " "	2.40%	4.26%
0-500 " "	3.75%	5.05%
0-600 " "	4.10%	5.85%
0-700 " "	)	6.34%
0-800 " "	) Unsafe to test	6.63%
0-900 " "	) at these pressures	7.23%
0-1000 " "	)	7.62%

*Equipment available reached maximum output at this pressure.

HYT-001 B

TYPES AND PROPERTIES OF 'HYTREL'

HYTREL thermoplastic polyester elastomers are available in pellet and powder (35 mesh) form. The polymers are processed at temperatures between 175 and 235°C depending on polymer type and process. Several hardness grades covering the durometer range from 40D (92A) to 70D (flexural modulus from 55 to 585 MPa) are available. HYTREL is available in 25 kg multi-wall paper bags with a moisture barrier inner wall. The bulk density factor is about 705 kg/m³. The 3 mm diameter pellets flow well in hoppers and material handling equipment.

Listed herein are key physical properties and characteristics of the various grades of HYTREL. Also included are data on masterbatches which can be used to enhance selected properties.

* Du Pont's registered trademark

SUMMARY OF CURRENT COMMERCIAL GRADES BASIC PROPERTIES[a]

(Please refer to Ref. HYT-Bulletin for other details)

Type of HYTREL	Typical Hardness Shore D (D-2240)	S.G. D-792	Melt Index (D-1238)		Minimum Process Melt Temp. °C	Typical Properties (ASTM D-638)				
			2.16 kg g/10 min.	Test Temp. °C		Tensile at Break MPa	Elong. at Break %	Stress at: Yield MPa	5% Strain MPa	10% Strain MPa
4056	40	1.16	5.30	190	168	28.0	550	6.20	2.30	3.70
G-4074	40	1.18	5.20	190	190	13.80	170	—	2.30	4.0
G-4766	47	1.16	11.15	230	215	21.0	500	8.70	3.50	4.80
G-4774	47	1.20	12.0	230	212	20.60	275	—	3.80	6.0
5526	55	1.20	18.0	220	215	34.50	500	13.70	6.90	10.70
G-5544	55	1.22	12.50	230	220	31.0	375	—	6.0	9.20
5556	55	1.20	5.90	220	215	35.80	450	—	6.90	10.70
5555 HS	◄— Properties are generally similar to HYTREL 5556									
G-6356	63	1.22	8.50	230	225	—	—	19.0	9.0	13.0
7246	72	1.25	12.50	240	225	45.50	400	27.0	14.0	20.0
HTG-4275	55	1.16	1.80	230	215	40.0	360	16.60	5.0	8.0
HTG-5612-B	50	1.16	3.0	230	215	36.0	530	—	4.40	7.20

[a] Not intended to be used for specifications. Physical property data obtained using injection moulded samples.

When using HYTREL in outdoor applications the proper type and amount of ultraviolet screening agents must be used. For detailed information, see bulletin HYT-303 A, "Pigmentation and Wheathering Protection of HYTREL", HYT-154, "HYTREL G-20 UV", HYT-163, "HYTREL G-41 CB".

HANDLING PRECAUTIONS

Before processing HYTREL, read bulletin HYT-201, "Handling and Processing Precautions for HYTREL", and observe the precautions recommended therein.

Compounding ingredients or additives may present hazards in handling and use. Before proceeding with any compounding or processing work, consult and follow label directions and handling precautions from suppliers of all ingredients.

Flexural Modulus R.T. (D-790) MPa	Vicat Softening (D-1525) °C	Ref. Literature HYT No.	Notes
55	108	102 (F2)	Moulding and extrusion grade. Colour stable
65	122	158	Lower cost. Moulding and extrusion grade with higher crystallisation rate. Yellowing
109	159	152	Moulding and extrusion grade. Colour stable
115	174	164	Lower cost. Moulding and extrusion grade with higher crystallisation rate. Yellowing
207	180	110	Moulding grade. Colour stable
195	196	165	Low cost moulding and extrusion grade with higher crystallisation rate. Yellowing
207	180	111	Extrusion grade, adequate for some moulding applications. Colour stable
→	→	105	Heat stabilized 5556 for prolonged exposure to temperature exceeding 120°C. Yellowing
300	195	157	Moulding and extrusion grade. Colour stable.
585	207	109 A	Moulding and extrusion grade. Colour stable.
160	174	155	High melt viscosity. Blow moulding grade, but also suitable for other extrusion techniques. Black colour (Natural colour available on request)
124	155	156	

HYTREL MASTERBATCHES

Type	Description	Average Let-Down Ratio Pts/100 HYTREL	Ref. Literature HYT No.	Notes
G-30 HS	Heat Stabiliser Concentrate	5	160	—
G-20 UV	Concentrate UV Light Stabiliser	3	154	Suitable for natural or coloured products
HTG-4450	Flame Retardant Concentrate	10	151	—
_10 MS	Hydrolysis Stabiliser Concentrate	10	114	Provide good extract when processing
G-41 CB	Carbon Black Concentrate UV Stabiliser	2.5	163	Replaces HTR-4659

3

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Except where otherwise noted, the information contained herein is based on a limited amount of our own laboratory work, employing small-scale equipment but following generally known trade practices. Although this information is believed to be accurate, these limitations must be kept in mind, because use of different conditions or equipment might produce substantially different results.

Because we cannot anticipate all variations in manufacturing equipment and methods, our products discussed herein are sold without warranty, express or implied, as to the results the user may obtain with them, and on the express understanding that purchasers will make their own tests to determine for themselves the suitability of such products for their particular purposes. Moreover, any statements herein concerning possible uses for our products are not to be considered a recommendation to use these products in the infringement of any patent

DU PONT

Hytrel
POLYESTER ELASTOMER

HYT-504A

FLUID AND CHEMICAL RESISTANCE OF 'HYTREL'

The data tabulated in this report document the effects of a broad variety of chemicals, solvents, oils and hydraulic fluids on HYTREL polyester *elastomer*[1]. *A summary guide to the chemical resistance of* HYTREL is presented in Table I. As a general rule, the resistance of HYTREL elastomers to fluids and chemicals increases as the hardness of the polymer increases (see Table II). Stress-strain and volume increase data for 40D, 55D, 63D and 72D grades of HYTREL following immersion in a variety of fluids are listed in Tables III thru VI.

Resistance to Various Classes of Fluids

HYTREL has excellent resistance to non-polar materials such as oils and hydraulic fluids, even at elevated temperatures. If necessary, resistance to hot oils can be further enhanced by heat-stabilization. The superior hot-oil aging resistance of heat-stabilized types such as HYTREL 5555 HS[2] is described in other literature (see HYT-105).

HYTREL is resistant to most polar fluids—such as acids, bases, amines and glycols—at room temperature. However, its resistance to polar fluids is poor at temperatures of 70°C [158°F] or above. HYTREL should not be used in service that requires continuous exposure to these fluids at elevated temperatures.

Resistance of HYTREL to hot moist environments is good. Hydrolytic stability can be further improved, if desired, by incorporating HYTREL 10MS[3] as a stabilizer. Recommendations covering the use of HYTREL 10MS are presented in other literature (see HYT-114).

HYTREL vs Some Other Thermoplastics

In general, HYTREL is resistant to the same classes of chemicals and fluids as are polyurethanes, both ester and ether based. However, HYTREL has better high temperature properties than the polyurethanes, and can be used satisfactorily at higher temperatures in the same fluids. For example, after exposure at 150°C [302°F] for 7 days in ASTM Oil No. 1, 55D HYTREL swells only about 2%, and retains 60% of its original tensile strength and 90% of its original elongation: polyurethanes of equivalent hardness degrade in less than a week at the same conditions.

HYTREL polyester elastomers do not contain an extractable plasticizer, as do flexible vinyls, certain grades of nylon and many rubber compounds. Many fluids and chemicals will extract the plasticizer from these materials, causing a significant increase in stiffness (modulus) and volume shrinkage. For example, a plasticized nylon of approximately 63D hardness undergoes a two-fold increase in modulus and shrinks about 10% when exposed to ASTM Oil No. 1 for 7 days at 121°C [250°F]. HYTREL of the same hardness shows no change in modulus and swells approximately 0.3% under the same exposure conditions.

[1,2,3] These superscript numbers refer to the proprietary materials list, p. 11

HANDLING PRECAUTIONS

The Du Pont Company is not aware of any health hazards with HYTREL polyester elastomers as shipped in pellet or powder form. However, there are some hazards that may be encountered during processing [illegible] recommended temperatures and holdup [illegible] are exceeded to the point where serious polymer degradation occurs. These are thermal burns, "blow back" fire and exposure to tetrahydrofuran vapor. For a complete discussion of the hazards associated with processing, please refer to [illegible] HYT-2[illegible] "Handling and Processing Precautions for HYTREL" and observe the precautions recommended therein.

Compounding ingredients or additives used with HYTREL to provide finished products may present hazards in handling and use. Before proceeding with any compounding or processing work, consult and follow label directions and handling precautions from suppliers of all ingredients.

Reg. U.S. Pat. & Tm. Off. [illegible]

Table I

Chemical Resistance Guide For HYTREL

The data tabulated below summarize the effects of a broad variety of fluids on HYTREL polyester elastomers. As a general rule the resistance of HYTREL elastomers to fluids and chemicals increases as the polymer hardness increases. **Unless otherwise noted the ratings shown in the table apply to all hardness grades.**

Rating Key: A—Fluid has little or no effect
B—Fluid has minor to moderate effect
C—Fluid has severe effect
T—No data—likely to have minor effect
X—No data—likely to have severe effect

Ratings are at 22°C [72°F] unless otherwide specified. Concentrations of aqueous solutions are saturated, except where noted.

We emphasize that the data contained herein should be used as a **guide only.** The tabulation is based primarily on laboratory tests but **does not** take into account all variables than can be encountered in actual use. Therefore it is advisable to test the material under actual service conditions before specification. If this is not practical, tests should be devised that simulate service conditions as closely as possible.

CHEMICAL	RATING
Acetic Acid, 20%	A
Acetic Acid, 30%	A
Acetic Acid, Glacial	A
Acetic Acid, Glacial (38°C) [100°F]	B
Acetic Anhydride	T
Acetone	B
Acetylene	A
Aluminum Chloride Solutions	T
Aluminum Sulfate Solutions	T
Ammonium Chloride Solutions	A
Ammonium Hydroxide Solutions	T
Ammonium Sulfate Solutions	B (40, 55, 63D)
Ammonium Sulfate Solutions	A (72D)
Amyl Acetate	B
Amyl Alcohol	A
Aniline	C
ASTM Oil No. 1 (149°C) [300°F]	A
ASTM Oil No. 3 (149°C) [300°F]	A
ASTM Reference Fuel A (70°C) [158°F]	A
ASTM Reference Fuel B (70°C) [158°F]	A
ASTM Reference Fuel C	A
ASTM Reference Fuel C (70°C) [158°F]	B (40, 55D)
ASTM Reference Fuel C (70°C) [158°F]	A (63, 72D)
Asphalt	T
Barium Hydroxide Solutions	T
Beer	A
Benzene	B (40, 55D)
Benzene	A (63, 72D)
Borax Solutions	A
Boric Acid Solutions	A
Bromine, Anhydrous Liquid	X
Butane	A
Butyl Acetate	B (40, 55D)
Butyl Acetate	A (63, 72D)
Calcium Chloride Solutions	A
Calcium Hydroxide Solutions	T
Calcium Hypochlorite, 5%	A

CHEMICAL	RATING
Carbon Bisulfide	B (40, 55D)
Carbon Bisulfide	A (63, 72D)
Carbon Dioxide	A
Carbon Monoxide	A
Carbon Tetrachloride	C (40D)
Carbon Tetrachloride	B (55, 63D)
Carbon Tetrachloride	A (72D)
Castor Oil	B (40, 55D)
Castor Oil	A (63, 72D)
Chlorine Gas, Dry	X
Chlorine Gas, Wet	X
Chloroacetic Acid	X
Chlorobenzene	X
Chloroform	C (40, 55D)
Chloroform	B (63, 72D)
Chlorosulfonic Acid	C
Citric Acid Solutions	A
Copper Chloride Solutions	A
Copper Sulfate Solutions	A
Cottonseed Oil	A
Cyclohexane	A
Dibutyl Phthalate	A
Diethyl Sebacate	A
Dioctyl Phthalate	A
Epichlorohydrin	X
Ethyl Acetate	B (40, 55, 63D)
Ethyl Acetate	A (72D)
Ethyl Alcohol	A
Ethyl Chloride	C (40, 55D)
Ethyl Chloride	B (63, 72D)
Ethylene Dichloride	C (40, 55D)
Ethylene Dichloride	B (63, 72D)
Ethylene Glycol	A
Ethylene Oxide	A
Ferric Chloride Solutions	T
Fluosilicic Acid	T

CHEMICAL	RATING
Formaldehyde, 40%	B
Formic Acid	B
FREON 11[9]	A
FREON 12	A
FREON 113 (55°C) [130°F]	A
FREON 114	A
Gasoline	A
Glue	A
Glycerin	A
n-Hexane	A
Hydrazine	C
Hydrochloric Acid, 20%	B
Hydrochloric Acid, 37%	C
Hydrocyanic Acid	T
Hydrofluoric Acid, 48%	X
Hydrofluoric Acid, 75%	X
Hydrofluoric Acid, Anhydrous	X
Hydrogen	A
Hydrogen Sulfide	A
Isooctane	A
Isopropyl Alcohol	A
JP 4 Jet Fuel	A
Kerosene	T
Lacquer Solvents	B (40, 55D)
Lacquer Solvents	A (63, 72D)
Lactic Acid	T
Linseed Oil	T
Lubricating Oils	A
Magnesium Chloride Solutions	T
Magnesium Hydroxide Solutions	T
Mercuric Chloride Solutions	T
Mercury	A
Methyl Alcohol	A
Methyl Ethyl Ketone	B (40, 55D)
Methyl Ethyl Ketone	A (63, 72D)
Methylene Chloride	C
Mineral Oil	A
Naphtha	A
Naphthalene	B (40, 55D)
Naphthalene	A (63, 72D)
Nitric Acid, 10%	B
Nitric Acid, 30%	C
Nitric Acid, 60%	C
Nitric Acid, 70%	C
Nitric Acid, Red Fuming	C
Nitrobenzene	C
Oleic Acid	A
Oleum 20-25%	C

CHEMICAL	RATING
Palmitic Acid	A
Perchloroethylene	C (40, 55D)
Perchloroethylene	B (63, 72D)
Phenol	C
Pickling Solution (20% Nitric Acid, 4% HF)	X
Pickling Solution (17% Nitric Acid, 4% HF)	X
Potassium Dichromate Solutions	T
Potassium Hydroxide Solutions	A
PYDRAUL 312[9]	A
Pyridine	X
SAE 10 Oil	A
Sea Water	A
Silicone Grease	A
SKYDROL 500B[10]	A
Soap Solutions	A
Sodium Chloride Solutions	A
Sodium Dichromate, 20%	T
Sodium Hydroxide, 20%	A
Sodium Hydroxide, 46½%	B
Sodium Hypochlorite, 5%	A
Soybean Oil	T
Stannous Chloride, 15%	T
Steam (100°C) [212°F]	B
Steam (110°C) [230°F]	C
Stearic Acid	T
Styrene	X
Sulfur, Molten	T
Sulfur Dioxide, Liquid	T
Sulfur Dioxide, Gas	T
Sulfuric Acid, up to 50%	A
Sulfuric Acid, above 50%	C
Sulfuric Acid, Fuming (20% Oleum)	C
Sulfurous Acid	B
Tannic Acid, 10%	A
Tartaric Acid	T
Tetrahydrofuran	B (40, 55D)
Tetrahydrofuran	A (63, 72D)
Toluene	B (40, 55D)
Toluene	A (63, 72D)
Trichloroethylene	C (40, 55D)
Trichloroethylene	B (63, 72D)
Triethanolamine	C
Trisodium Phosphate Solution	A
Tung Oil	T
Water (70°C) [158°F]	A
Water (100°C) [212°F]	B
Xylene	B (40, 55D)
Xylene	A (63, 72D)
Zinc Chloride Solutions	A

Table II

Effect of Hardness on Chemical and Fluid Resistance of HYTREL

Fluid	Immersion Time, days	Immersion Temperature °C [°F]	Volume Increase, %			
			40D HYTREL	55D HYTREL	63D HYTREL	72D HYTREL
• **Oils and Hydraulic Fluids**						
ASTM Oil No. 1	7	100 [212]	2	2	<1	<1
ASTM Oil No. 3	7	100 [212]	23	11	6	4
Ethylene Glycol	7	22 [72]	<1	<1	<1	<1
PYDRAUL 312[9]	7	100 [212]	110	31	20	15
SKYDROL 500B[10]	7	100 [212]	–	22	15	–
• **Solvents and Fuels**						
ASTM Ref. Fuel C	7	22 [72]	50	24	15	9
n-Butyl Alcohol	7	22 [72]	18	11	5	2
CELLOSOLVE Acetate[4]	7	22 [72]	40	19	13	6
Iso-octane	7	22 [72]	8	5	<1	<1
Methyl Isobutyl Ketone	7	22 [72]	42	19	14	6
Xylene	7	22 [72]	88	36	20	13
• **Halocarbons**						
FREON 113[5]	7	22 [72]	19	7	2	<1
Perchloroethylene	7	22 [72]	81	32	19	10
Trichloroethylene	7	22 [72]	Dissolved	67	41	25
• **Acids and Bases**						
Acetic acid, glacial	7	38 [100]	No data	39	22	16
Acetic acid, 5%	7	38 [100]	No data	<1	<1	<1
Formic acid, conc.	7	22 [72]	57	31	No data	No data
Formic acid, 50%	7	22 [72]	11	8	No data	No data
Sodium Hydroxide, 20%	7	22 [72]	<1	<1	<1	<1
Sulfuric acid, 20%	7	22 [72]	<1	<1	<1	<1

Table III

Fluid and Chemical Resistance of 40D HYTREL Polyester Elastomer

Original Properties[a] at 22°C [72°F]	Tensile Strength	25.5 MPa [3700 psi]
	Elongation	450%
	100% Modulus	7.6 MPa [1100 psi]

Fluid	Immersion Time, days	Immersion Temperature, °C [°F]	Tensile Strength, % of original retained after immersion[a]	Elongation, % of original retained after immersion[a]	100% Modulus, % of original retained after immersion[a]	Volume Increase, %
• Oils and Hydraulic Fluids						
ASTM Oil No. 1	7	22 [72]	100	101	99	<1
ASTM Oil No. 1	7	100 [212]	83	103	111	2
ASTM Oil No. 3	7	22 [72]	99	107	95	8
ASTM Oil No. 3	7	100 [212]	78	96	100	23
Crude oil, Algerian	3	70 [158]	108	101	No data	21
PYDRAUL 312[9]	7	22 [72]	90	112	78	40
PYDRAUL 312[9]	7	100 [212]	50	104	44	110
URSA oil[11]	7	22 [72]	112	110	100	1
URSA oil[11]	7	100 [212]	93	104	110	5
• Solvents and Fuels						
ASTM Reference Fuel B	7	22 [72]	100	104	84	28
ASTM Reference Fuel B	7	70 [158]	78	96	93	36
ASTM Reference Fuel C	7	22 [72]	62	110	67	50
ASTM Reference Fuel C	7	70 [158]	47	89	53	88
n-Butyl alcohol	7	22 [72]	82	113	91	18
CELLOSOLVE Acetate[4]	7	22 [72]	83	110	78	40
Isooctane	7	22 [72]	106	104	101	8
Methyl isobutyl ketone	7	22 [72]	57	81	81	42
Xylene	7	22 [72]	57	74	75	88
• Halocarbons						
FREON 113[5]	7	22 [72]	99	107	67	19
Perchloroethylene	7	22 [72]	73	98	58	81
Trichloroethylene	7	22 [72]	Dissolved			
• Acids and Bases						
Formic acid, conc.	7	22 [72]	47	94	49	57
Formic acid, 50%	7	22 [72]	58	108	66	11
Formic acid, 25%	7	22 [72]	72	110	85	5
Formic acid, 10%	7	22 [72]	71	114	86	2
Sodium hydroxide, 20%	7	22 [72]	100	103	77	<1
Sulfuric acid, 20%	7	22 [72]	91	100	74	<1
• Miscellaneous						
Dimethyl formamide	7	22 [72]	85	111	82	39
Ethylene glycol	7	22 [72]	76	102	82	<1
Nitromethane	7	22 [72]	65	103	59	33
WESSON oil[12]	7	22 [72]	90	102	102	<1

[a]These properties were measured at room temperature at a strain rate of 5[illegible] mm/min [2 in/min] on dumbbells died from slabs injection molded under standard [illegible]

Table IV

Fluid and Chemical Resistance of 55D HYTREL Polyester Elastomer

Original Properties at 22°C [72°F]	Tensile Strength	39.3 MPa [5700 psi]
	Elongation	350%
	100% Modulus	17.2 MPa [2500 psi]

Fluid	Immersion Time, days	Immersion Temperature, °C [°F]	Tensile Strength, % of original retained after immersion[b,c]	Elongation, % of original retained after immersion[b,c]	100% Modulus, % of original retained after immersion[b,c]	Volume Increase, %
• **Oils and Hydraulic Fluids**						
ASTM Oil No. 1	7	100 [212]	94	100	No data	2
ASTM Oil No. 1	7	121 [250]	100	109	No data	2
ASTM Oil No. 1	7	150 [302]	97	125	No data	2
ASTM Oil No. 2	7	100 [212]	108	105	No data	7
ASTM Oil No. 2	7	121 [250]	105	109	No data	8
ASTM Oil No. 2	7	150 [302]	95	118	No data	11
ASTM Oil No. 3	7	100 [212]	104	107	101	11
ASTM Oil No. 3	7	121 [250]	102	109	102	13
ASTM Oil No. 3	7	150 [302]	61	86	103	18
Automatic transmission fluid,						
Type A	7	100 [212]	109	130	No data	5
Type A	7	121 [250]	110	109	No data	6
Type A	7	150 [302]	105	123	No data	8
Type A	14	150 [302]	60	89	No data	9
Automatic transmission fluid,						
Type F	7	100 [212]	104	100	No data	5
Type F	7	121 [250]	101	103	No data	6
Type F	7	150 [302]	92	131	No data	8
HARMONY Oil No. 41[6]	7	100 [212]	101	98	No data	3
HARMONY Oil No. 41[6]	7	121 [250]	104	103	No data	4
HARMONY Oil No. 41[6]	7	150 [302]	35	8	No data	−3
HOUGHTO-SAFE 620[7]	7	70 [158]	95	96	No data	<1
HOUGHTO-SAFE 620[7]	14	70 [158]	95	103	No data	<1
PYDRAUL 312[9]	7	100 [212]	90	91	98	31
PYDRAUL 312[9]	7	121 [250]	77	91	93	40
PYDRAUL 312[9]	14	121 [250]	80	101	No data	41
SKYDROL 500B[10]	7	100 [212]	72	80	95	22
SKYDROL 500B[10]	7	121 [250]	<10	<10	–	32
• **Solvents and Fuels**						
ASTM Reference Fuel C	7	22 [72]	93	94	91	24
ASTM Reference Fuel C	7	70 [158]	105	102	92	31
n-Butyl alcohol	7	22 [72]	116	100	80	11
CELLOSOLVE Acetate[4]	7	22 [72]	95	94	80	19
Isooctane	7	22 [72]	106	94	86	5
Methyl isobutyl ketone	7	22 [72]	103	97	80	19
Xylene	7	22 [72]	103	97	77	36
• **Halocarbons**						
Carbon tetrachloride	7	22 [72]	94	94	69	32
FREON 113[5]	7	22 [72]	[illegible]	105	91	7
Perchloroethylene	7	22 [72]	96	[illegible]	84	32
Trichloroethylene	7	22 [72]	[illegible]	[illegible]	77	67
• **Acids and Bases**						
Acetic acid, glacial	7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Acetic acid, 5%	7	[illegible]	[illegible]	[illegible]	96	[illegible]
Formic acid, conc.	7	22 [72]	[illegible]	[illegible]	74	[illegible]
Formic acid, 50%	7	22 [72]	[illegible]	[illegible]	70	[illegible]

Table IV (cont.)

Fluid	Immersion Time, days	Immersion Temperature, °C [°F]	Tensile Strength, % of original retained after immersion	Elongation, % of original retained after immersion	100% Modulus, % of original retained after immersion	Volume Increase, %
Formic acid, 25%	7	22 [72]	95	105	86	4
Formic acid, 10%	7	22 [72]	100	109	88	2
Sodium hydroxide, 20%	7	22 [72]	95	106	95	<1
Sulfuric acid, 20%	7	22 [72]	92	106	100	<1
• Miscellaneous						
Aniline	7	22 [72]	51	64	44	93
Dibutyl phthalate	7	22 [72]	110	97	83	12
Diethylene glycol	7	22 [72]	101	97	79	1
Dimethyl formamide	7	22 [72]	98	94	76	19
Dioctyl phthalate	7	22 [72]	121	112	91	3
Ethylene glycol	7	22 [72]	101	94	86	<1
Nitromethane	7	22 [72]	100	109	89	17
Toluene diisocyanate (mixed isomers)	7	22 [72]	97	90	67	41
WESSON oil[11]	7	22 [72]	98	94	87	<1

These properties were measured at room temperature at a strain rate of 51 mm/min [2 in/min] on dumbbells died from slabs injection-molded under standard conditions

These values are based on unmodified HYTREL, the superior hot oil aging of heat stabilized types such as HYTREL 5555 HS is covered in other literature

Table V
Fluid and Chemical Resistance of 63D HYTREL Polyester Elastomer

Original Properties[b] at 22°C [72°F]	
Tensile Strength	37.9 MPa [5500 psi]
Elongation	450%
100% Modulus	13.8 MPa [2500 psi]

Fluid	Immersion Time, days	Immersion Temperature, °C [°F]	Tensile Strength, % of original retained after immersion[d]	Elongation, % of original retained after immersion[d]	100% Modulus, % of original retained after immersion[d]	Volume Increase, %
• Oils and Hydraulic Fluids						
ASTM Oil No. 1	7	100 [212]	86	101	No data	<1
ASTM Oil No. 1	7	121 [250]	79	107	97	<1
ASTM Oil No. 1	7	150 [302]	83	104	94	<1
ASTM Oil No. 1	14	121 [250]	82	90	No data	<1
ASTM Oil No. 1	14	150 [302]	70	119	No data	<1
ASTM Oil No. 2	7	100 [212]	90	99	No data	3
ASTM Oil No. 2	7	121 [250]	88	101	No data	4
ASTM Oil No. 2	7	150 [302]	81	99	No data	5
ASTM Oil No. 3	7	100 [212]	89	112	No data	6
ASTM Oil No. 3	7	121 [250]	93	106	128	7
ASTM Oil No. 3	7	150 [302]	56	57	94	10
ASTM Oil No. 3	14	121 [250]	56	18	No data	7
ASTM Oil No. 3	14	150 [302]	17	1	No data	9
Automatic transmission fluid,						
Type A	7	100 [212]	100	101	No data	3
Type A	7	121 [250]	97	99	111	3
Type A	7	150 [302]	78	114	109	4
Type A	14	150 [302]	55	91	No data	5
Automatic transmission fluid,						
Type F	7	100 [212]	94	101	No data	2
Type F	7	121 [250]	92	103	94	3
Type F	7	150 [302]	76	111	97	3
HARMONY Oil No. 41[6]	7	100 [212]	88	106	No data	1
HARMONY Oil No. 41[6]	7	121 [250]	96	103	No data	2
HARMONY Oil No. 41[6]	7	150 [302]	Failed	Failed	Failed	–
HOUGHTO-SAFE 620[7]	7	70 [158]	101	105	No data	<1
HOUGHTO-SAFE 620[7]	14	70 [158]	74	114	No data	<1
ORONITE 8200[8]	7	121 [250]	86	91	No data	1
ORONITE 8200[8]	14	121 [250]	76	88	No data	2
ORONITE 8200[8]	7	150 [302]	67	77	No data	2
ORONITE 8200[8]	14	150 [302]	49	67	No data	4
PYDRAUL 312[9]	7	100 [212]	88	110	No data	20
PYDRAUL 312[9]	7	121 [250]	79	101	No data	23
PYDRAUL 312[9]	14	121 [250]	94	111	No data	24
SKYDROL 500B[10]	7	100 [212]	82	91	97	15
SKYDROL 500B[10]	7	121 [250]	17	<10	–	21
• Solvents and Fuels						
ASTM Reference Fuel B	7	22 [72]	96	94	97	6
ASTM Reference Fuel B	7	50 [122]	88	92	91	12
ASTM Reference Fuel C	7	22 [72]	84	92	89	15
ASTM Reference Fuel C	7	50 [122]	80	85	83	18
N Butyl alcohol	7	22 [72]	112	104	86	5
CELLOSOLVE Acetate[4]	7	22 [72]	107	96	79	13
Isooctane	7	22 [72]	103	100	100	<1
JP-4 jet fuel	7	22 [72]	[illegible]	94	[illegible]	[illegible]
JP 4 jet fuel	7	38 [100]	[illegible]	86	92	4
Methyl isobutyl ketone	7	22 [72]	103	95	89	14
Xylene	7	22 [72]	106	95	84	[illegible]

Table V (cont.)

Fluid	Immersion Time, days	Immersion Temperature, °C [°F]	Tensile Strength, % of original retained after immersion[a]	Elongation, % of original retained after immersion[a]	100% Modulus, % of original retained after immersion[a]	Volume Increase, %
• **Halocarbons**						
Carbon tetrachloride	7	22 [72]	109	92	81	23
FREON 113[5]	7	22 [72]	100	89	83	2
Perchloroethylene	7	22 [72]	101	88	80	19
Trichloroethylene	7	22 [72]	88	82	66	41
• **Acids and Bases**						
Acetic acid, glacial	7	38 [100]	105	95	79	22
Acetic acid, 5%	7	38 [100]	103	90	81	1
Sodium hydroxide, 20%	7	22 [72]	75	68	94	<1
Sodium hydroxide, 10%	7	22 [72]	69	67	97	<1
Sulfuric acid, 20%	7	22 [72]	104	99	94	<1
Sulfuric acid, 10%	7	22 [72]	106	97	94	<1
• **Miscellaneous**						
Aniline	7	22 [72]	75	78	61	52
Dibutyl phthalate	7	22 [72]	110	89	88	1
Dimethyl formamide	7	22 [72]	102	96	80	16
Ethylene glycol	7	22 [72]	109	104	95	<1
Toluene diisocyanate (mixed isomers)	7	22 [72]	110	97	87	16
WESSON oil[12]	7	22 [72]	102	102	93	<1

[a] These properties were measured at room temperature at a strain rate of 51 mm/min [2 in/min] on dumbbells died from slabs injection-molded under standard conditions.

Table VI

Fluid and Chemical Resistance of 72D HYTREL Polyester Elastomer

Original Properties at 22°C [72°F]		
	Tensile Strength	39.3 MPa [5700 psi]
	Elongation	350%
	100% Modulus	17.2 MPa [2500 psi]

Fluid	Immersion Time, days	Immersion Temperature, °C [°F]	Tensile Strength, % of original retained after immersion*	Elongation, % of original retained after immersion*	Volume Increase, %
• Oils and Hydraulic Fluids					
ASTM Oil No. 1	7	121 [250]	83	62	<1
ASTM Oil No. 1	7	150 [302]	98	88	1
ASTM Oil No. 3	7	121 [250]	92	62	5
ASTM Oil No. 3	7	150 [302]	83	31	6
Automatic transmission fluid, Type A	7	121 [250]	97	70	1
Type A	7	150 [302]	101	96	2
Automatic transmission fluid, Type F	7	121 [250]	98	74	2
Type F	7	150 [302]	99	94	2
PYDRAUL 312[9]	7	121 [250]	97	112	15
• Solvents and Fuels					
ASTM Reference Fuel B	7	22 [72]	102	104	4
ASTM Reference Fuel B	7	50 [122]	94	101	9
ASTM Reference Fuel C	7	22 [72]	99	104	9
ASTM Reference Fuel C	7	50 [122]	104	103	12
n-Butyl alcohol	7	22 [72]	108	112	2
CELLOSOLVE Acetate[4]	7	22 [72]	104	112	6
Isooctane	7	22 [72]	98	112	<1
JP-4 jet fuel	7	22 [72]	107	103	<1
JP-4 jet fuel	7	38 [100]	112	106	<1
Methyl isobutyl ketone	7	22 [72]	109	112	6
Xylene	7	22 [72]	99	101	13
• Halocarbons					
Carbon tetrachloride	7	22 [72]	109	109	7
FREON 113[5]	7	22 [72]	106	110	<1
Perchloroethylene	7	22 [72]	102	104	10
Trichloroethylene	7	22 [72]	98	93	25
• Acids and Bases					
Acetic acid, glacial	7	38 [100]	93	100	16
Acetic acid, 5%	7	38 [100]	107	113	<1
Sodium hydroxide, 20%	7	22 [72]	90	104	<1
Sodium hydroxide, 10%	7	22 [72]	109	110	<1
Sulfuric acid, 20%	7	22 [72]	110	117	<1
Sulfuric acid, 10%	7	22 [72]	102	110	<1
• Miscellaneous					
Aniline	7	22 [72]	82	88	31
Dibutyl phthalate	7	22 [72]	98	112	<1
Ethylene glycol	7	22 [72]	100	114	<1
Toluene diisocyanate (2,4 isomer)	7	22 [72]	110	104	6
WESSON oil[11]	7	22 [72]	101	110	1

*These properties were measured at room temperature at a strain rate of 51 mm/min [2 in/min] on dumbbells died from [illegible] standard conditions.

PROPRIETARY MATERIALS

Material	Composition	Supplier
(*1*) HYTREL* polyester elastomers—40, 55 63 and 72 durometer D hardness	Block copolymers of short-chain diol terephthalate and long-chain polyether diol terephthalate	Du Pont Company Elastomers Division Wilmington, DE 19898
(*2*) HYTREL 5555 HS	Specially-stabilized 55D HYTREL	
(*3*) HYTREL 10 MS	Concentrate of aromatic poly-carbodiimide in 40D HYTREL; 20% PCD by weight.	
(*4*) CELLOSOLVE* acetate solvent	Ethylene glycol monoethyl ether acetate	Union Carbide Corporation Chemicals and Plastics 270 Park Avenue New York, NY 10017
(*5*) FREON* refrigerants FREON 11 FREON 12 FREON 113 FREON 114	 Trichlorofluoromethane Dichlorodifluoromethane Trichlorotrifluoroethane Dichlorotetrafluoroethane	 Du Pont Company FREON Products Division Wilmington, DE 19898
(*6*) HARMONY Oil No. 41	Hydrocarbon oil	Gulf Oil Company—U.S. 1167 Gulf Building Addition Houston, TX 77002
(*7*) HOUGHTO-SAFE* 620 hydraulic fluid	Water/glycol fluid	E. F. Houghton & Company 303 West Lehigh Avenue Department 154 Philadelphia, PA 19133
(*8*) ORONITE* 8200 hydraulic fluid	Disiloxane fluid	Chevron Chemical Company Oronite Division 200 Bush Street San Francisco, Ca 94120
(*9*) PYDRAUL* 312 hydraulic fluid	Phosphate ester	Monsanto Company 800 North Lindbergh Boulevard St. Louis, MO 63166
(*10*) SKYDROL* 500B	Phosphate ester	
(*11*) URSA* oil	Petroleum oil	Texaco, Incorporated 135 East 42nd Street New York, NY 10017
(*12*) WESSON* oil	All-vegetable salad oil	Hunt-Wesson Foods, Inc. 1645 West Valencia Drive Fullerton, CA 92634

*Reg. U.S. Pat. & Tm. Off.

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Appendix C

DESIGN AND FABRICATION OF HIGH STRENGTH LIGHTWEIGHT COLLAPSIBLE PIPELINE

DESIGN AND FABRICATION OF HIGH

STRENGTH LIGHTWEIGHT COLLAPSIBLE

PIPELINE

Prepared For:

Naval Civil Engineering Laboratory
Port Hueneme, California

Under Contract:

N-62474-84-C-3144
Phase II, Part III

Prepared By:

Angus Fire Armour Corporation
P.O. Drawer 879
Angier-Kennebec Road and Broad Street
Angier, North Carolina 27501
USA

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ANGUS FIRE ARMOUR CORPORATION

1. Introduction

Phase II Part III of this contract was a continuation of development work to construct a high strength, lightweight collapsible pipeline for use in Navy fuel systems. The contract required that the following specific work to be performed:

1. Fabricate a low cost 6 inch polyester jacket of the modified weaving technique defined in Phase II, Part II "Feasibility Study on the use of aramid Yarns, ... Hoses". This jacket was used as a sample for testing extruding and weaving techniques.

2. After successfully defining extrusion and weaving techniques, in the appropriate monthly Progress Report, the contractor shall weave aramid jackets and extrude covers. These short lengths samples (two 20 foot, one 60 foot, one 10 foot) shall be used to determine: burst strength, tensile strength, elongation under tension, and inflated bend radius. The hoses shall be equipped with 6 inch NPT threaded end couplings, as previously provided under Phase II, Part I.

3. Design and initiate the development of a high strength coupling for use with the 6 inch aramid hose.

4. After testing, all samples shall be coupled and shipped.

Part I of the requirement was completed successfully. Part 2 was unsuccessful. An Aramid hose was produced but not in sufficient lengths to meet delivery requirements. The hose produced also failed to meet goals set. Extensive redesign of the jacket and extrusion techniques were tried in order to more closely meet the goals. These efforts were only limitedly successful.

This report is a summary of the work conducted. The report is arranged to discuss the various areas which were examined. In the appendix is a summary of each trial run made and the results of the run.

Drawings for part 3 are also included in this report. Couplings were shipped coupled to a length of polyester hose.

2. Coating Selection

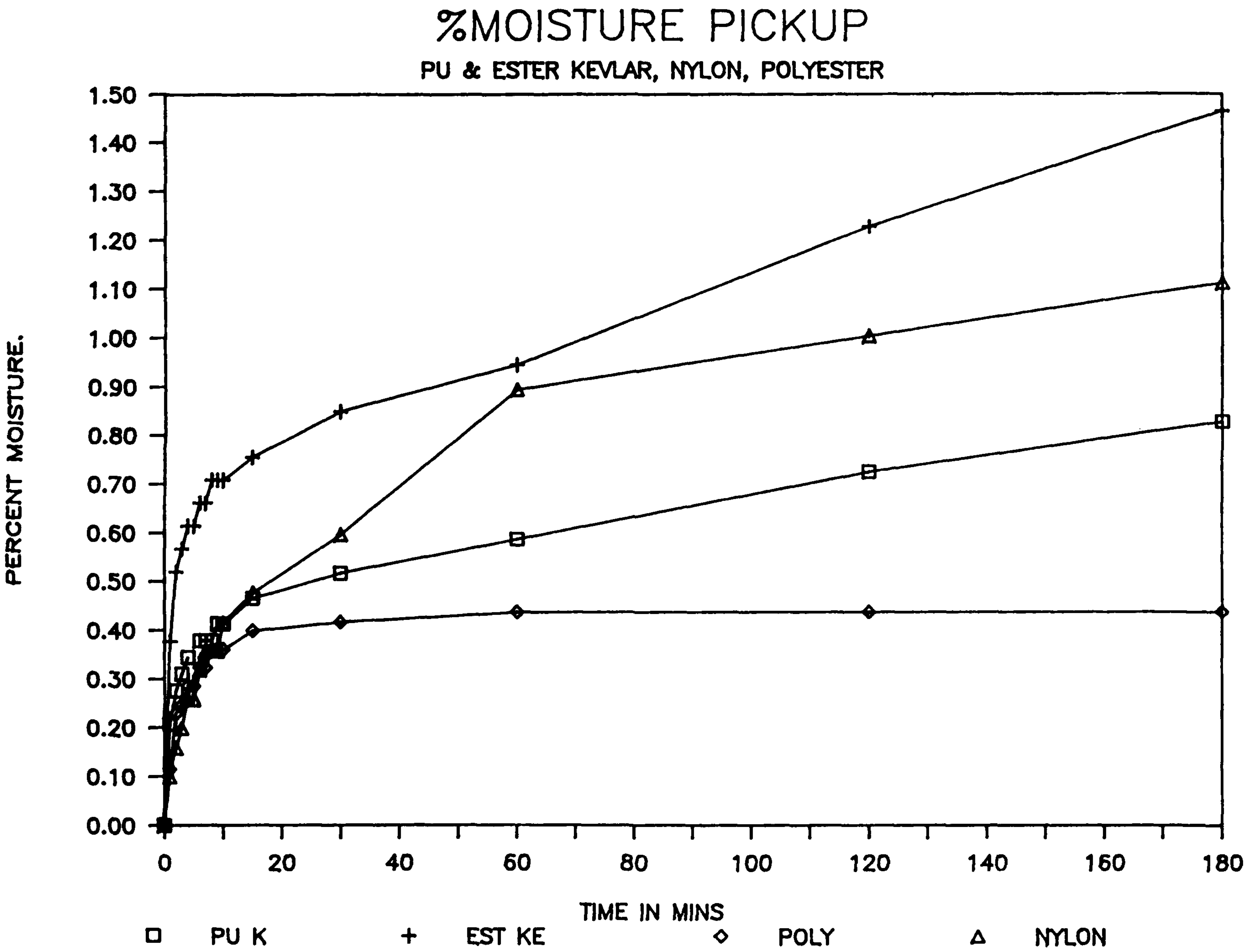
Moisture regain of aramid yarns was a factor that was discussed in previous reports as a major obstacle to be overcome for a successful extrusion. The extrusion process requires that the jacket must not contain moisture or other substances that will flash off when suddenly heated by hot elastomer in the extrusion head. If sufficient quantities of these substances are present, they will erupt through the elastomer as the hose exits the extrusion head and result in blistering of the cover and/or the lining. The jacket is typically dried on the extrusion line just prior to entering the extrusion head. Conventional hose of polyester and nylon are known to extrude without blistering after being dried with the existing predrying equipment. Two coatings of aramid yarns were reviewed to try to approximate the moisture absorption characteristics of polyester and nylon yarns.

The first coating reviewed was Esterweld (Isocyanate) on the yarn from Bibb Corporation. The second coating was a polyurethane coating supplied by Synthetic Thread Corporation. Samples of both yarns were dried at 110° C for three hours. The samples were then removed from the oven and placed in ambient air (approximately 75°F and 50% R.H.). The weight increase versus time was recorded. A plot of this data is shown in graph 1. Similar test were made with polyester and nylon. These results are also shown in graph 1. The polyurethane aramid coated yarn showed moisture regain characteristics that were better than nylon while the Esterwell coating was considerably worse than both uncoated polyester and nylon yarns. Thus, the polyurethane coating was selected.

In addition to moisture protection, the polyurethane coating also offered abrasion protection for the yarn during weaving. No noticeable adverse effects on the looms were noted. The yarn did have a tendency to stick together slightly on the bobbins.

The coating increased the denier of the yarn by approximately 7% and measurements of the jacket thickness to determine tooling sizes was made more difficult as a result. The jacket thickness decreased after being heated as a result of the coating softening and being deformed. Thus measurement to determine tooling sizes had to be taken with the jacket heated.

Graph 1



%MOISTURE PICKUP
PU & ESTER KEVLAR, NYLON, POLYESTER
PERCENT MOISTURE.
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
20
40
60
80
100
120
140
160
180
TIME IN MINS
□ PU K
+ EST KE
◇ POLY
△ NYLON

3. Jacket Design and Yarn Selection

Jacket design was based on data obtained from the 4 inch trials conducted under phase II part II of this contract. The selection of yarn size was very critical since only one chance was afforded by the contract and no changes in yarn size or construction could be made once selected. A polyester jacket was first designed to approximate the proposed aramid design. The design was based on the expected strength of aramid cabled yarn as provided by Dupont. This design is shown in Table 1. Actual burst test of this design was 550 psi. Tensile strength as reported by NCEL was 47000 pounds. A summary of the hose is shown in Table 2.

Following the successful extrusion of the polyester jacketed test hose, efforts were turned to obtain aramid yarn. The E.I. Dupont Corporation is the only available source of aramid yarn in the U.S.A. Dupont produces several versions of aramid which are sold under the trade name of "Kevlar". After consulting Dupont, Kevlar 29 was selected for use in the hose since it offered the best choice in elongation and lowest moisture regain.

A study was made to determine the best twisting methods for aramid. Three factors were considered in this study - strength, elongation, and fatigue. Aramid in comparison to nylon or polyester has very high strength, very low elongation and poor fatigue resistance. Only the high strength characteristic is desirable in the hose jacket. Thus, twisting methods were reviewed that would provide maximum strength, maximum elongation, and best fatigue resistance.

In conversations with E.I. Dupont the indication was given that the tire and belting industry use cabled yarn with very high twist level. These high twist levels (TM = 6)* give improved fatigue life to aramid and generally increased extensibility. Unfortunately, strength conversion is very poor. Thus with high twist levels, more yarn would have to be added to the jacket to obtain the same initial strength. The jacket as designed with 478 warp ends already contained the maximum yarn content that could be woven by conventional weaving methods on conventional looms. Any reduction in individual yarn strength would result in a reduction of the theoritical burst and tensile strength since no additional yarn could be added.

* $TM = \frac{\text{Turns / Inch} \times \sqrt{\text{Denier}}}{73}$

Table 1 Calculations for Polyester Test Jacket with Comparison to Aramid Yarn Twisted at Dupont Lab

Diameter @ Centerline of Jacket = 6.25

Warp		Polyester	Dupont twisted* Aramid
Yarn Grams/Denier	=	8.1	23
No Ends	=	478	478
Denier / Plies	=	1000/8	1500/5
Yarn Efficiency Factor	=	.95	.95
BRK Strength Yarn	=	136 pounds	361
% Fill	=	73%	73%
Hose Efficiency Factor	=	70%	60%
Break Strength	=	45367 pounds	103523
Weft (Fill Yarn)			
Yarn Grams/Denier	=	8.1	23
Cabled Yarns / In	=	20	20
Denier / Plies	=	1000/8	1500/5
Yarn Efficiency Factor	=	.95	.95
BRK Strength Yarn	=	136 pounds	361
% Fill	=	89%	89%
Hose Expansion @ Burst	=	23%	4%
Hose Efficiency Factor	=	80%	80%
Burst	=	564 psi	1777 psi

* The aramid strength shown were later found to not be obtainable from commercial twisters. Thus modifications to this design were later required.

Table 2 Test Results of Polyester Test Hose used to Establish Extrusion Parameters

Hose O.D. = 6.24
Hose I.D. = 5.969
Hose Weight / Ft = 1.227 lbs/ft

	Hose Wall Thickness	Cover Thickness	Lining Thickness
	.111	.015	.024
	.124	.020	.017
	.149	.044	.018
	.146	.019	.017
Average	.132	.024	.019

Short length burst pressure = 550 psi

Tensile strength = 47000 pounds
(Reported by NCEL)

Bend Radius (no end load)

20	psi	12 1/2	ft
40	psi	10	ft
60	psi	10	ft
80	psi	9	ft
100	psi	6	ft
120	psi	5	ft

500 feet of this hose was sent to USN/CEL who requested that a performance specification be written around this hose design.

Numerous samples of twisted aramid yarn were obtained from Dupont, Bibb Corporation and Synthetic Thread Corporation with various twist levels. Each were tested for strength and elongation. The results are shown in Table 3. No test was made for fatigue. Based on conversations with Dupont, the high twist levels were assumed to improve fatigue.

Considerable variations were noted between yarn twisted by Dupont versus the other commercial twisters. Yarn twisted by Dupont showed consistently higher strength. Unfortunately Dupont did not have enough capacity to supply yarn for this project.

The final selection of twist levels was a compromise to try to obtain good strength conversion with as high a twist level as possible. Unfortunately the strength level was found to be less than previously thought when the polyester test jacket was woven. A slight revision to the jacket design was made and shown in table 4.

The selected construction was a cabled construction consisting of 1 yarn twisted on itself with a "Z" twist and then 5 of the single twisted yarns twisted in an "S" direction. Graph 2 supplied by Dupont indicated that best strength levels could be obtained by twisting the single yarn one half turn per inch more than the final cable yarn twist level. This relation of twist levels was followed in the final yarn selection for warp. Several different twist levels were selected for the weft yarn since weft changes could be made very easily while weaving the hose.

Yarn was ordered from Synthetic Thread Corporation. Table 5 shows the quantity of yarn ordered. The amount ordered would provide enough yarn to weave in theory approximate 2000 feet of jacket. Expected losses were 10% in weaving and 100 feet for each extrusion try. This amount of aramid was felt to provide sufficient yarn to meet contract goals unless a large number of unsuspected problems occurred.

Table 3 Properties of Test Samples of Cabled Aramid

Source	Denier/ Single Ply/ Cable Ply	Twist Tpi	Break Strength Lbs.	Ten Gram / Denier	Elong. @brk. %	Total Denier	Tested By
Bibb	1500/2/3	4.9x4.6	350	15.5	5.6	10243	Bibb
Dupont (CR-702)	1420/1/5	6.3x2.8	320	18.6	3.1	7821	Dupont
Synthetic Thread	2250/1/5	5.2x2.6	410	15.5		12000	Angus
Dupont (CR-702)	2250/1/5	5.2x2.6	492	18.7	3.6	11954	Dupont
Dupont (CR-702)	2250/1/5	5.2x5.2	439	15.2	5.0	13113	Dupont
Dupont (CR-702)	2250/1/5	5.2x3.8	504	18.5	4.3	12360	Dupont
Dupont (CR-702)	2250/1/5	3.2x2.0	529	20.4	3.2	11756	Dupont
Synthetic Thread	2250/1/5	5.6x4.2	415	15.1	4.7	12461	Dupont
Synthetic Thread	2250/1/5	5.6x2.9	471	17.9	4.0	11950	Dupont
Dupont (CR-702)	2250/1/5	4.2x3.8	494	18.7	3.9	11972	Dupont
Dupont (CR-702)	1500/1/5	4.2x3.8	351	20.9	3.4	7689	Dupont
Dupont (CR-702)	1500/1/5	3.2x2.8	367	22.1	3.1	7532	Dupont
Dupont (CR-702)	2250/1/5	3.2x2.8	535	20.9	3.3	11587	Dupont
Synthetic Thread	1500/1/5	3.3x2.8	335	18.8	3.1	8074	Dupont
Synthetic Thread	1500/1/5	3.3x2.8	331	18.6	3.1	8066	Dupont
Dupont (Contractor)	1500/1/5	4.2x3.8	334	19.0	3.4	7988	Dupont
Dupont (Contractor)	2250/1/5	4.2x3.8	480	18.2	3.9	11961	Dupont
Bibb (Not Cabled)	1500/2	1.5x-	108	-	2.7	3178	Angus
Bibb	1000/2/4	3.9x3.9	270	-	6.4	9138	Angus
Synthetic Thread	2250/1/5	5.2x4.0	395	-	6.2	12454	Angus
Angus U.K. (Not Cabl	1500/5	2.69	252	-	-	-	Angus (UK)
Dupont (Wax Coated)	2260/1/5	2	490	-	2.05	-	Dupont
Synthetic Thread	2250/1/5	5.2x2.6	405	-	5.6	-	Angus
Bibb	1500/1/5	6.3x2.5	276	-	4.4	-	Angus
Angus U.K.	1500/4/4	2.3x1.2	1043	-	-	-	Angus (UK)

Table 4 Calculations for Selected Aramid Jacket using Commercial Available Yarn Strength

Diameter @ Centerline Jacket	= 6.25 inch
Warp	
Yarn GR/Denier	= 22
No Ends	= 478
Denier / single plys / cabled ply	= 1500/1/5
Yarn Efficiency Factor	= 93%
Break Strength of Yarn	= 338 pounds
% Fill	= 70%
Hose Efficiency Factor	= 60%
Break Strength Hose	= 97000 pounds
Weft	
Yarn GR/Denier	= 22
Cabled Yarns / In	= 18
Denier / Single Ply / Cabled Ply	= 2250/1/5
Yarn Efficiency Factor	= 93%
Break Strength Yarn	= 507 pounds
% Fill	= 95%
Hose Expansion @ Burst	= 4%
Hose Efficiency Factor	= 70%
Burst	= 1966 psi

Table 5 Yarns Ordered For Aramid Jacket Hose

Warp - 478-1500/1/5 with 3.3Z, 2.8S twist

Theoretical tensile - 173722 lbs.
Expected tensile - 97000 lbs.
Space fill - .70 in / in
Weight - .36 lbs/ft

Weft - 2250/1/5 varying twist, 18 cabled ply / in with 2 in 1 insertion

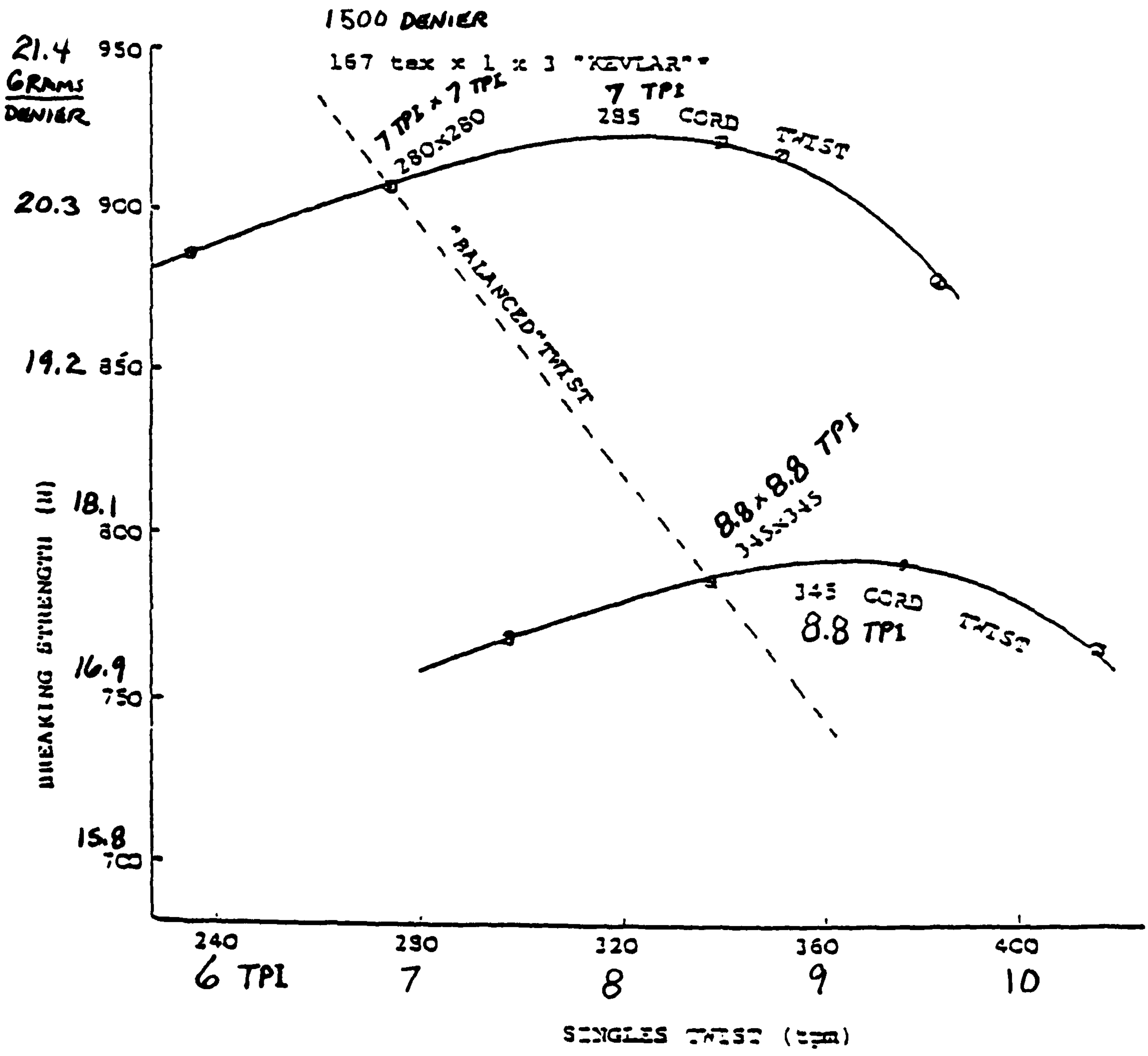
Theoretical burst - 3020 psi
Expected burst - 1966 psi
Space fill - .95 in/in
Weight - .32 lbs/ft

Need to Order:

QTY	Spool Size	Yarn	Twist	Ft. Bobbin	Ft. Jacket	Total Lbs.
485	1 1/2 lb	1500/1/5	3.3Z x 2.8S	2510	1990	728
168	2 1/2 lb	2250/1/5	3.3Z x 2.8S	2790	1312	420
24	2 1/2 lb	2250/1/5	4.2Z x 3.8S	2790	188	60
24	2 1/2 lb	2250/1/5	5.2Z x 4.0S	2690	180	60
24	2 1/2 lb	2250/1/5	5.2Z x 2.6S	2790	188	60
24	2 1/2 lb	2250/1/5	3.3Z x 2.0S	2790	188	60

GRAPH 2

EFFECT OF OFF-BALANCE TWIST ON CORD BREAKING STRENGTH



SOURCE - W. P. COOPER
E.I. DUPONT DENEMOURS
WILMINGTON, D.E. 19898

TPI = TURNS/INCH

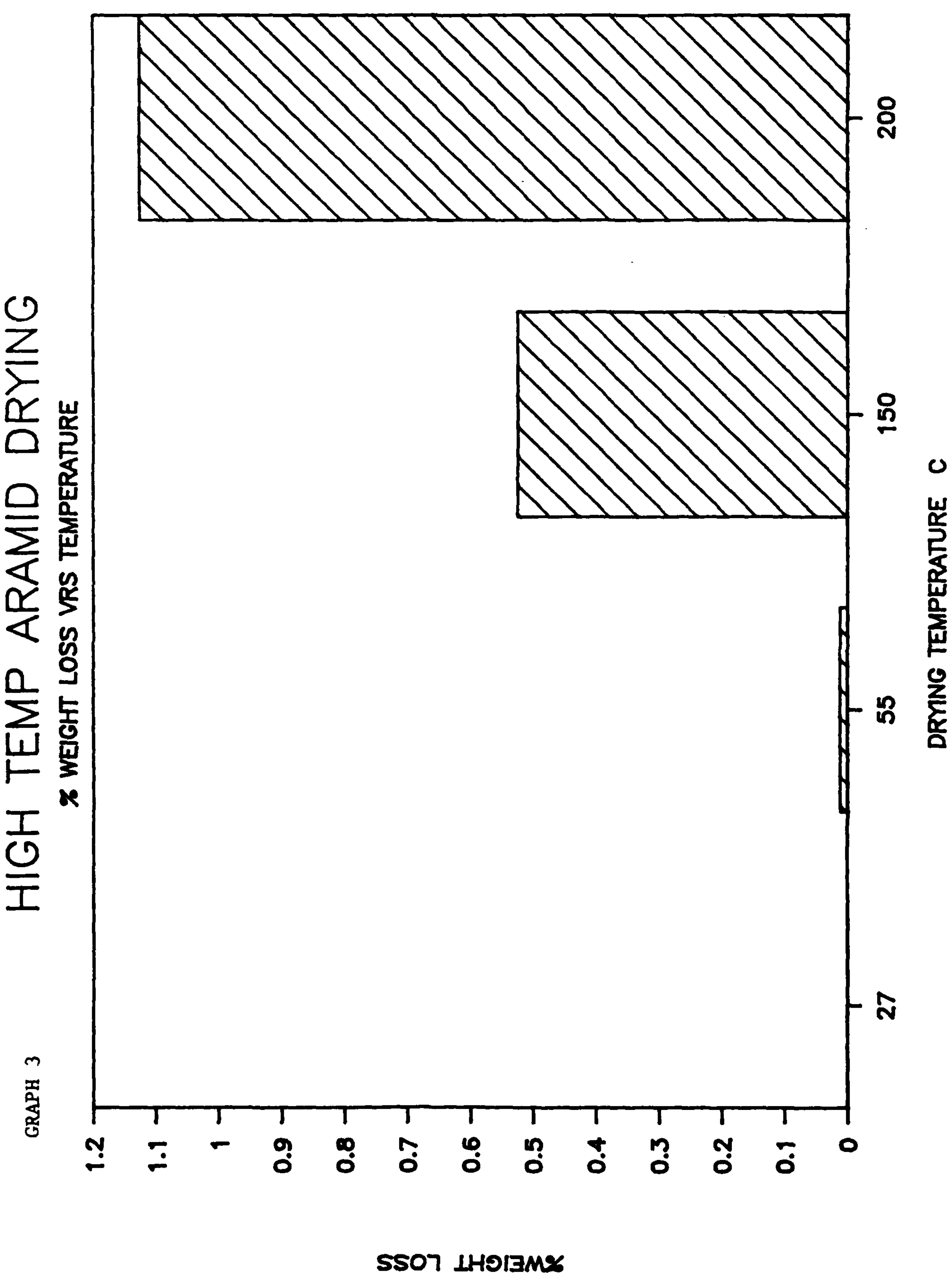
* Du Pont's registered trademark

4. Extrusion Blistering

Despite efforts to eliminate moisture from the aramid jacket, the first extrusion run of aramid was not successful. Extreme blistering of the elastomer occurred as the hose exited the extrusion head. The conclusion was drawn that moisture was not completely the problem and several quick test in the lab revealed that fact to be true. A sample was dried in the lab at the normal predrying temperature of 77°C for 2 days. The sample was then taken up to the normal predrying extrusion temperature of 150°C for 7 hours, then taken to the temperature of the thermoplastic in the extrusion head, 200°C, for 1 hour. Graph 3 shows the weight reduction versus temperatures. Clearly additional substances were driven off at the 200°C temperature. This fact was also further supported by the observation of smoke coming from the oven at the elevated temperature. The assumption was made that these substances were finishing oils used by Dupont in the aramid finishing process which Dupont later confirmed advising that finishing oils were used that would flash off at 170°C.

As a result of this test, modifications were made to the extrusion line to enable predrying at 200°C. This modification proved successful and an aramid hose was extruded with no blistering.

GRAPH 3


HIGH TEMP ARAMID DRYING
% WEIGHT LOSS VRS TEMPERATURE
%WEIGHT LOSS
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
27
55
150
200
DRYING TEMPERATURE C

5. Aramid Strength Losses

Burst test were conducted on samples of the successfully xtruded aramid hose. The short length burst test was 1050 psi. This result was well below the theoretical design. An overall hose strength loss of 35% was expected for burst. The actual loss was 65%.

An analysis was made to determine where strength losses occurred during the hose construction cycle. Weft yarn was pulled from jacket at various stages of the construction cycle and checked for strength. By analysis, strength losses in the various stages could be estimated. The analysis showed that a 33% loss occurred in weft strength of the standard twill weave after drying at 230°C but prior to extrusion. By comparing to non woven yarn dried at 230°C and to non dried woven yarn, a break down of the 33% was made. This break down showed that weaving accounted for a 12% loss and high temperature drying for 11%. The remaining 10% loss was attributed to losses incurred by drying the aramid under high crimp. The high crimp places the fibers in a high stress state and Dupont verified that Kevlar under high stress at high temperatures will experience high strength loss.

Weaving trials were conducted to construct a jacket that did not tightly crimp the weft yarn. The loom was modified to provide a warp weaving pattern of 1 up / 5 down (Warp yarn passes over the top of 1 weft yarn and then below 5 weft yarns while weaving on the loam). This pattern reduced the amount of crimp placed on the yarn. The same test was conducted on the jacket as conducted on the twill weave. The results indicated almost no loss in strength due to weaving and approximately 20% loss after heating. The above distribution of strength loss is summarized in Tables 6 and 7.

Attempts to extrude this 1 up / 5 down jacket were unsuccessful. The jacket was found to be very stiff, extremely tight and thin, with the result that the elastomer could not be forced through the weave. This jacket design was abandoned.

Additional modifications were made to the loom such that a pattern of 11 up / 11 down was woven. The jacket turned out to be very open with little crimp. No strength test was conducted on this design.

Table 6 Weft Strength Loss In Aramid Jacket

Weave Type	On Weft Bobbin (lbs)	Undried Woven Jacket (lbs)	% Strength Loss	Dried 230 C (lbs)	% Strength Loss
Non Woven	494	-		439	11
Twill Weave	492	435	12	328	33
5 Dn/1 Up (1)	489	493	0	407	17
5 Dn/1 Up (2)	489	507	0	382	22
5 Dn/1 Up (3)	492	471	4	368	25
5 Dn/1 Up (4)	492	489	1	387	21
5 Dn/1 Up (5)	492	485	1	398	19

Table 7 Distribution of Aramid Hose Weft Losses

	Twill Weave	1 up / 5 down Weave
Weaving	12%	0%
High Temperature Drying	11%	11%
Crimp on Yarn	10%	9%
Extrusion Damage and Loading EFF	32%	?
Total	65%	?

6. Conclusions

The goal of this contract was to produce a through-the-weave aramid hose with a burst of 1800 psi and a tensile of 100,000 pounds. Despite careful preliminary work and calculations, such a hose was not produced. In the beginning, the chief concern was to overcome blistering problems that had occurred in previous trials. Those problems were overcome and a through-the-weave hose was successfully extruded. However, strength losses in the extrusion process were extremely high and the hose did not meet its intended goals. The chief reason for the failure was the inability of aramid to retain its strength when crimped tightly in a woven jacket and subjected to high drying temperatures.

Weaving modifications to the jacket were tried that would reduce the crimp on the aramid yarn and thus improve the strength losses. These modifications were a departure from the conventional jacket weaving patterns. Attempts to extrude these jackets were unsuccessful primarily due to extrusion tooling design. Additional development time would be necessary to perfect the tooling to extrude these jackets.

Aramid now appears to be less attractive as a material for high strength through-the-weave hose. The high strength losses that occurred during extrusion could probably be overcome with more development work. However, the low extensability is still a very serious concern. Polyester jacketed hoses are designed with safety factors of 3 to 4. Thus a hose with a short length burst of 600 psi will have a working pressure of 150 to 200 psi. These safety factors have been found through experience to be adequate to cover hose flaws and unknown operating conditions such as water hammer. A polyester jacket hose creates relatively low pressure surges from water hammer due to its ability to expand under pressure. An aramid hose, on the other hand, can be expected to create very high pressure surges due to water hammer since it expands very little. Safety factors will, by necessity, have to be much higher with factors as high as 10 not being unrealistic. Thus a aramid hose with a burst of 1800 psi could in the final design have an operating pressure no better than much lower burst polyester hose. Such characteristics when combined with the extremely high cost of aramid make the material questionable for hose jacket.

Appendix I

Summary of Actual Trial Runs

TRIAL RUN 1 - Polyester Hose

Date: 02/23/87

Jacket Construction - Twill Weave Polyester with 2 in 1 insertion

Warp - 478 ends, 1000 Denier, 8 ply

Weft - 20 Cabled yarns / in, 2 in 1 insertion; 1000 denier, 8 ply - 1½ TPI S

Jacket Plug Diameter - 6 9/32 Dia

Weft Lengths - 516/520 mm

Wall Thickness - .096" - .102"

Results -

This run was a standard checkout run using polyester jacket. No lining was produced in the hose. An evaluation of the internal parts of the extruder head indicated incorrect sizing. The run was stopped after, about 100 feet of jacket was used.

ANGUS FIRE ARMOUR CORPORATION

TRIAL RUN 2 - Polyester Hose

Date: 2-25-87

Jacket Construction - Twill Weave Polyester

Warp - 478 ends, 1000 Denier, 8 ply

Weft - 20 cabled yarns / in, 2 in 1 insertion; 1000 denier, 8 ply - 1½ TPI S

Jacket Plug Diameter - 6 9/32 Dia

Weft Lengths - 516/520 mm

Wall Thickness - .096" - .102"

Results -

This run produced approximately 600 feet of relatively good hose. The hose I.D. was 5 31/32" with wall thickness varying from .111" thick to .149". Adjustments to tooling size would need to be made to produce more uniform wall thickness. The end of the jacket was woven with aramid weft yarn in the place of polyester. No special precaution or change in procedure was made during extrusion for this part of the jacket. The hose blistered immediately as the extruded hose exited the extrusion head.

TRIAL RUN 3 - Aramid 1st Run

Date: 07/25/87

Jacket Construction - Twill Weave Aramid with 2 in 1 Weft Insertion

Warp - 478 ends, 1500 Denier, 1 ply single, 5 ply cable - 3.3Z TPI/ 2.8S TPI

Weft - 18 cabled yarns / in, 2 in 1 insertion; 2250 denier, 1 ply single, 5 cable - 3.3Z TPI / 2.8 S TPI

Jacket Plug Diameter - 6 13/64"

Results -

The aramid jacket was predried for 48 hours at 77°F. The jacket was packed in desiccant to remove all moisture and protected while being fed onto the jacket feeder. A dehumidifier was used to dry air around the jacket feeder. The dryer was set at the standard 150°F drying temperature. Despite all preventions, the hose blistered profusely as the hose exited the extrusion head. No usable hose was produced.

ANGUS FIRE ARMOUR CORPORATION

TRIAL RUN 4 - Aramid 2nd Run

Date: 07/29/87

Jacket Construction - Twill Weave Aramid with 2 in 1 Weft Insertion

Warp - 478 ends, 1500 Denier, 1 ply single, 5 ply cable - 3.3 Z TPI/ 2.8 S TPI

Weft - 18 cabled yarn / in, 2 in 1 insertion; 2250 denier, 1 ply single, 5 cable - 3.3 Z TPI / 2.8 S TPI

Jacket Plug Diameter - 6 13/64"

Results -

Procedures were changed for this run. The jacket dryer was wrapped with 1½" of additional insulation. A fan was added to cool the terminal block connections to the electric heaters for the dryer. The temperature in the dryer was increased to 230°C. Considerable smoke discharged from the dryer as the jacket passed. No blistering was observed as the hose exited the extrusion head. The walls of the hose was very irregular and the lining was thin. The hose was pressure tight and a burst test was conducted. Burst was very low - 1050 PSI. Further evaluation revealed that tooling was oversize. The jacket thickness was found to decrease after heating due to the softening of polyurethane coating on the aramid yarn. This run was a significant milestone in that it proved that aramid could in fact be extruded by through-the-weave extrusion. However, obtaining goals of the design would be difficult.

TRIAL RUN 5 - Special Weave

Date: 08/26/87

Jacket Construction - Special Weave of 1 Up - 5 Down Construction

Warp - 478 ends, 1500 Denier, 1 ply single, 5 ply cable - 3.3 Z TPI/ 2.8 S TPI

Weft - 18 cabled yarns / in, 2 in 1 insertion; 2250 denier, 1 ply, 5 cable - 3.3 Z TPI / 2.8 S TPI

Jacket Plug Diameter - 6 13/64

Wall Thickness - .095" cold - .080" heated

Results -

This trial was an attempt to run a special weave that reduced crimp on the yarn. The jacket was found to be a very tight weave construction. This jacket too, thinned considerably when heated. The cold thickness was .095" when compressed. The heated dimension was .080" compressed. No lining was produced at all. Head pressure was very low (200 PSI) due to clearance in the extrusion tooling being incorrect as a result of the jacket decreasing in thickness under heat. Investigation of the jacket resulted in the conclusion that even alteration in the tooling dimensions may still result in no lining and thus, this weave pattern was abandoned.

ANGUS FIRE ARMOUR CORPORATION

TRIAL RUN 6 - Special Loose Weave

Date: 10/28/87

Jacket Construction - Special Weave of 11 Up - 11 Down Construction

Warp - 478 ends, 1500 Denier, 1 ply single 5 ply cable - 3.3 Z TPI/ 2.8 S TPI

Weft - 18 cabled yarns / in, 2 in 1 insertion; 2250 denier, 1 ply 5 cable - 3.3 Z TPI / 2.8 S TPI

Jacket Plug Diameter - 6 13/64"

Wall Thickness - See Results*

Results -

After considerable loom work, a jacket was woven with a pattern of 11 up, 11 down on the warp yarns. The construction was very loose and open. Determining the actual jacket thickness for tooling proved to be a very difficult problem. When heated and compressed the construction was .110". when measured by conventional gauges. The tooling was sized for that dimension. On extrusion start-up, the jacket was found to require very high haul off loads resulting in considerable damage and distortion to the weft yarns on the jacket. Thermoplastic passed through the jacket, but no lining or cover were formed. The extrusion run was finally stopped by the breakage of the main haul off pulley on the extruder. Several days were required to make repairs.

TRIAL RUN 6, Cont.

Results, cont.

Investigation of the run revealed that the true thickness of the jacket was in fact 0.150" when crushed over a larger area at approximately 30 psi loading. The overcrushing explained the high haul off load and the ultimate equipment failure.

The non crushed thickness was found to be as high as 0.208". The total hose thickness allowed by the die and tip clearance was only .185" resulting in the jacket springing back on exiting the die, allowing the weft to break through the thermoplastic forming the cover and lining.

TRIAL RUN 7 - Special Loose Weave

Date: 11/10/87

Jacket Construction - Special Weave of 11 Up - 11 Down Construction

Warp - 478 ends, 1500 Denier, 1 ply single 5 ply cable - 3.3 Z TPI/ 2.8 S TPI

Weft - 18 cabled yarn / in, 2 in 1 insertion; 2250 denier, 1 ply 5 cable - 3.3 Z TPI / 2.8 S TPI

Jacket Plug Diameter - 6 13/64

Wall Thickness - .150"

Results -

Methods of measuring jacket wall thickness were revised for this trial. Jacket thickness was measured by compressing the jacket over a 6 in^2 area with a load applied to provide approximately 20-40 PSI loading. Measurements were taken on unheated jacket and heated jacket. The jacket was found to be about 0.150" compressed while hot and tooling was sized to this figure.

The run resulted in absolutely no lining being formed. Extrusion head pressure was very low (less than 200 PSI). Investigation revealed that the internal parts of the extruder head did not seal to the jacket sufficiently to force the elastomer through the jacket. The woven jacket was so coarse that corridors were created that allowed elastomer to pass so freely to the cover that it was not forced through the weave to the lining. On Trial 6, the jacket was compressed tightly enough to force elastomer through the jacket.

This trial concluded the final run with Aramid.

Appendix II

Summary of Tests on 6" Polyester Hose used to Establish Extrusion Parameters

ANGUS FIRE ARMOUR CORPORATION

Elongation Test

1. Purpose
   The purpose of the test was to determine the elongation versus end load for the 6" NCEL Polyester test hose produced under contract N62474-84-C-3144.

2. Equipment
   Hose - 6" dia x 3 ft long uncoupled polyester jacket, polyurethane cover and lining, tested as extruded with no post sizing operations.

   Scales -

   Clamps - Angus standard Wellmaster clamps

3. Procedure
   The hose was clamped in standard Wellmaster clamps. One end was attached to a heavy weight placed on a scale. The other end was attached to a lifting source. Two marks were applied to the surface of the hose 24 inches apart. A lifting force was applied to the hose and the length between the two marks were measured.

4. Results
   Table 1 shows the result of the test. Graph 1 is a plot of % extrusion versus load.

5. Conclusions
   The results shown in Graph 4 are consistent with expected results. The hump observed between 400 pounds and 1000 pounds is consistent with existing hose and is the result of warp crimp being pulled out. At loads above 1000 pounds, the curve is linear and is the result of extension of the polyester warp.

Table 1 Hose Extension Data, Polyester Jacket

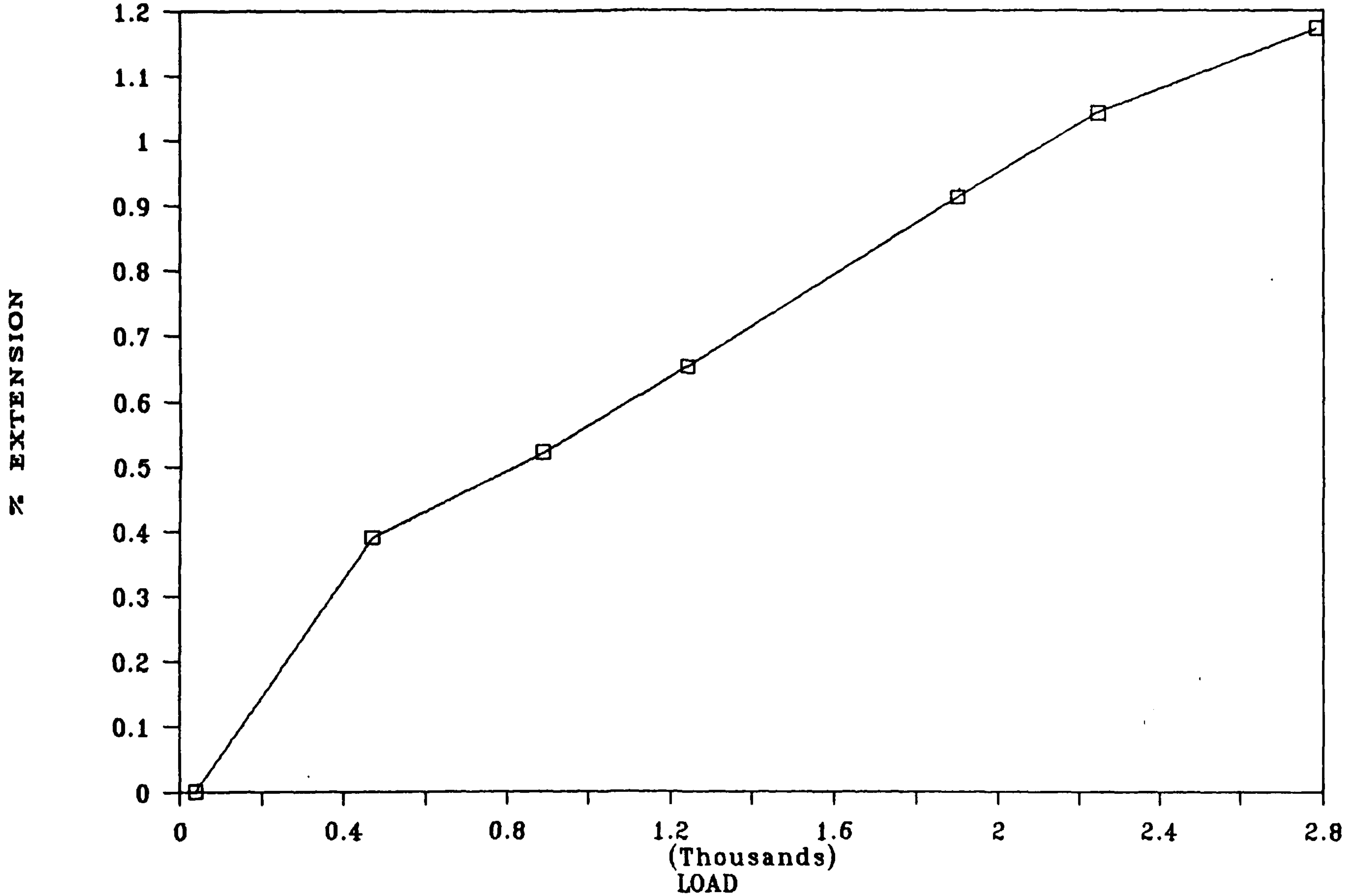
Load	Length	% Extension
38	24	0
472	24.094	.4
888	24.125	.5
1242	24.156	.7
1900	24.219	.9
2246	24.250	1.0
2782	24.281	1.2

Slope = 00041 % / pound
Intercept = .116 %

Graph 4

POLYESTER TEST HOSE

%EXTENSIBILITY



Bend Radius Test

1. Purpose
The purpose of this test was to obtain the bend radius versus internal pressure for the 6" NCEL polyester test hose run under contract N62474-84-C-3144.

2. Equipment
Hose - 6" x 24 ft nominal diameter polyester jacket, polyurethane cover and lining tested as extruded with no sizing operations.

   Pressure gauge - Angus gauge number 24 calibration 12-18-87.

3. Procedure
The hose was coupled with TWDS type barbed couplings and Band-It clamps. The hose was laid on a smooth, level concrete surface and filled with water to various pressures. One end was held rigid and the other end pulled around until a kink formed in the hose. A tape measure was then used to approximate the final radius and the result recorded. The procedure was repeated for various pressures.

4. Results - The following radii was measured for each internal pressure shown:

Internal Pressure	Bend Radius
20 psi	12.5 ft
40 psi	10 ft
40 psi	9.5 ft
60 psi	10 ft
60 psi	10 ft
80 psi	9 ft
80 psi	8.17 ft
100 psi	5.17 ft
100 psi	6 ft
120 psi	6 ft
120 psi	5 ft

5. Conclusion
The bend radii were found to be in line with expected results.

Short Length Burst Test

1. Purpose
   The purpose of this test was to determine the burst pressure of the 6" NCEL polyester test hose extruded under N62474-84-C-3144.

2. Equipment
   Angus burst tank located at Angus Fire Armour Corporation, Angier, NC.

   Hose - 6" diameter x 2 ft long polyester jacket, polyurethane cover and lining tested as extruded with no post sizing operations.

3. Procedure
   The hose was coupled with standard Angus Wellmaster couplings and attached to fitting in the Angus burst tank. The hose was then filled with water and pressurized quickly until rupture.

4. Results
   A clear weft rupture occurred at 550 psi.

5. Conclusion
   The results were in line with the expected results.

Appendix III

Relevant Dupont Literature

TWISTING

OF

KEVLAR® ARAMID

W. P. COOPER
E. I. DuPONT DeNEMOURS & CO.
INDUSTRIAL MARKETING-TECHNICA
WILMINGTON, DE 19898

Problem Areas

Yarn damage in singles twisting

Non-uniformity in cable twisting

Recommendations

Spindle Speeds, RPM	4000 - 5000	
Balloon Tensions, GMS @ 4000 RPM	Ply	Cable
1500/1/2	190-230	300-340
1500/1/3	190-230	450-500

Guide Surfaces

Matte finished chrome preferred

Ceramic - may damage yarn

Travelers

Nylon

Improved Strength

Y-thread line or volumetric arrangement during cable twisting

VARIABLES IN TWISTING

- TRAVELERS WITH METAL INSERTS
  - BROKEN FILAMENTS
  - HIGH TENSION AND HIGH TEMPERATURES
- NYLON TRAVELERS -
  - IMPROVED QUALITY
  - LOWER TENSION 1200 TO 600 GMS (5,200 RPM)
  - LOWER TEMPERATURE
  - CUT MORE EASILY - NEED FREQUENT INSPECTION AND CHANGE
- REDUCED SPINDLE SPEED
  - TRAVELER CUTTING MINIMIZED
  - TENSION REDUCED FROM 600 TO 450 GMS WHEN SPEED REDUCED FROM 5200 TO 4500 RPM (CABLE TWISTER)
  - YARN OR CORD QUALITY IMPROVED
- GUIDE SURFACES
  - CERAMIC - CAN CAUSE YARN DAMAGE
  - MATTE CHROME - QUALITY IMPROVED

Y-THREADLINE STRING-UP IN CABLE TWISTING FOR IMPROVED STRENGTH.

- ALLOWS TWIST TO BACK OUT OF SINGLES BEFORE CABLING TO GIVE MORE ORDERLY ARRANGEMENT OF FILAMENTS IN CORD BUNDLE
- GIVES MORE UNIFORM CORD WITH LESS VARIATION IN STRENGTH, ELONGATION AND MODULUS
- GIVES SIGNIFICANTLY HIGHER GRAY CORD STRENGTH AND BETTER TREATED CORD STRENGTH
- DESIRABLE FOR KEVLAR® BUT NOT NECESSARY FOR NYLON BECAUSE OF LOWER MODULUS AND HIGHER RETRACTION

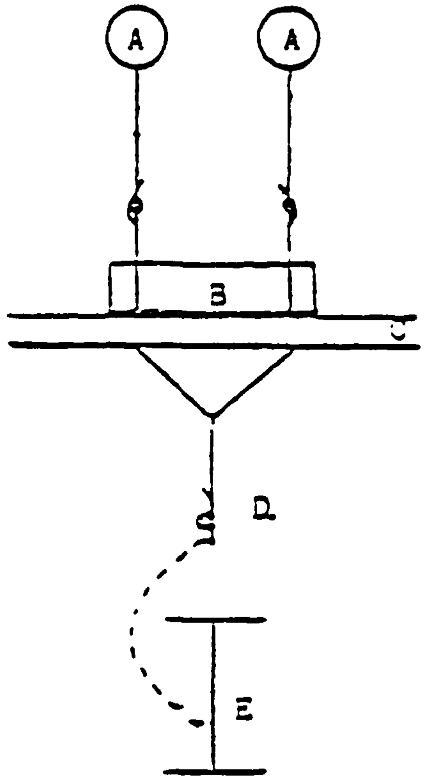
DU PONT LABORATORY
CABLE TWISTING "KEVLAR"
1500/3 7.2 X 7.2 TPI

STRING-UP	BREAK STRENGTH	
1. UNDIVIDED ON FEED ROLL NO BAR	179.4	18
2. "INVERTED Y-THREADLINE" DIVIDED ON FEED ROLL OVER BAR	173.3	
3. "Y-THREADLINE" DIVIDED ON FEED ROLL NO BAR	196.6	
4. DU PONT "ELONGATED Y" DIVIDED ON FEED ROLL OVER SPACED ROLLER GUIDES	203.4	

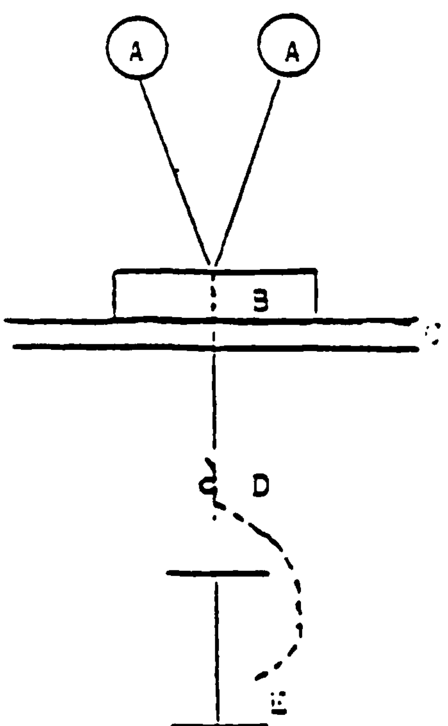
DIAGRAMMATIC SKETCH

CABLE TWISTING

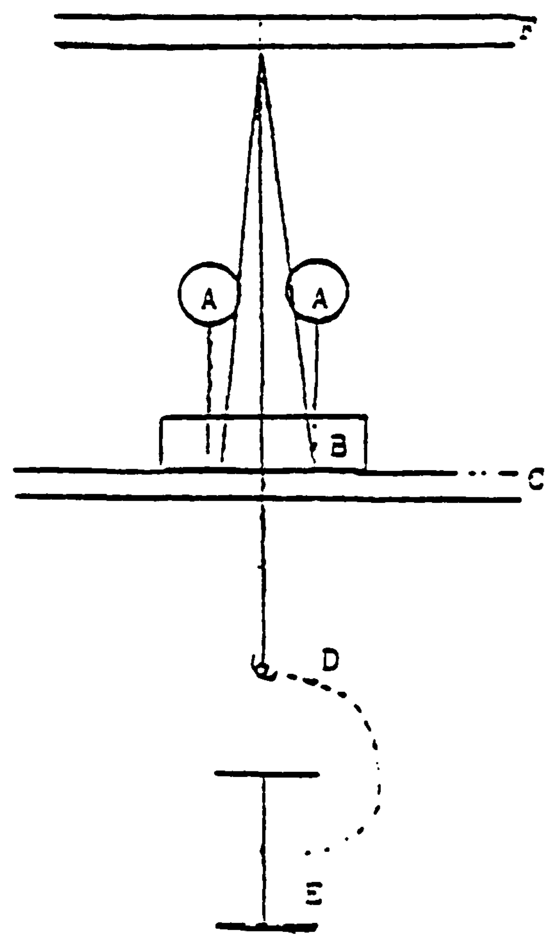
Y



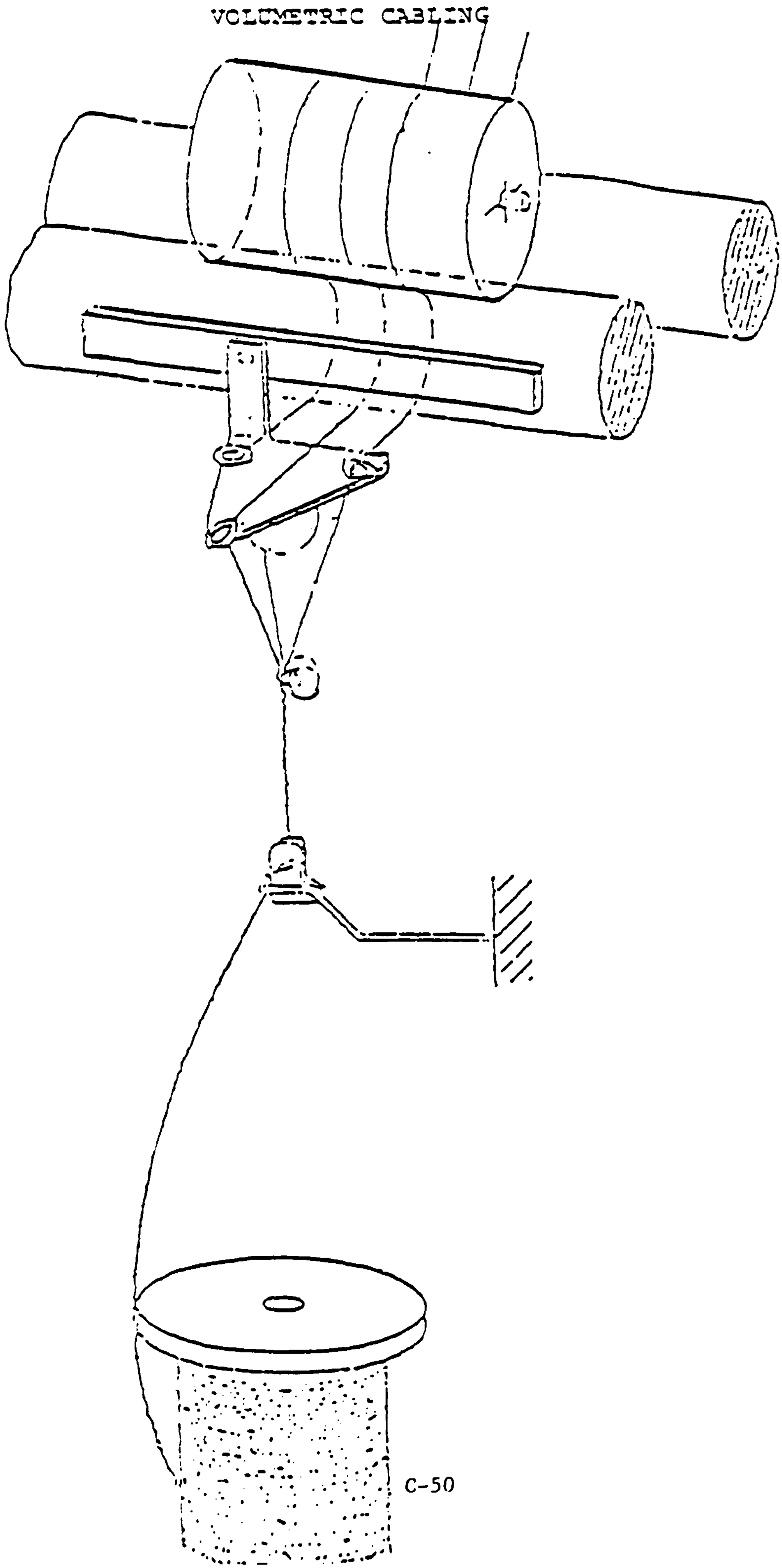
NON Y



INVERTED Y

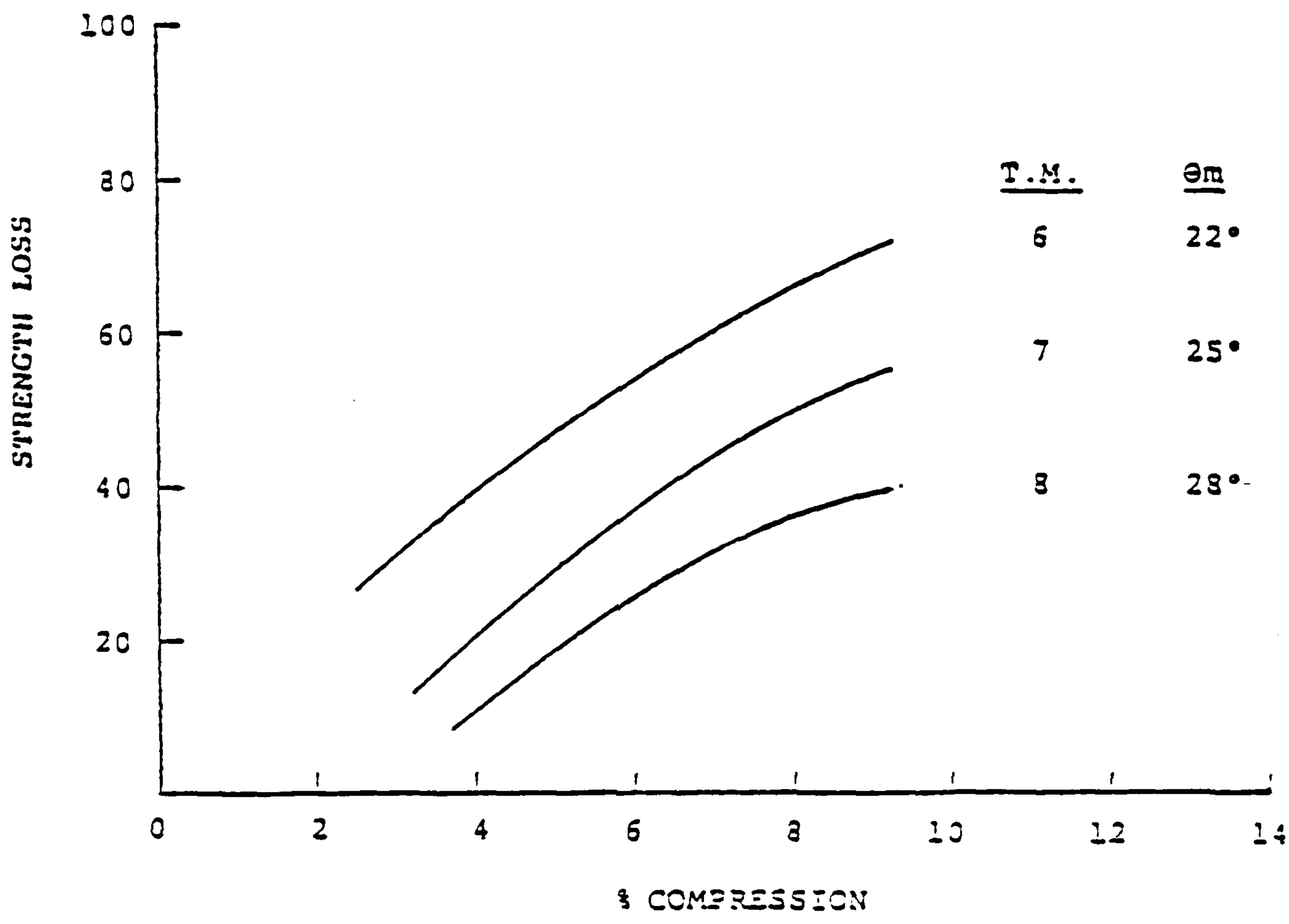


A. SINGLES YARN SUPPLY
B. WEIGHT ROLL ON FEED ROLL
C. FEED ROLL
D. PIGTAIL OVER SPINDLE
E. TAKE UP BOBBIN
F. GUIDE BAR


VOLUMETRIC CABLING

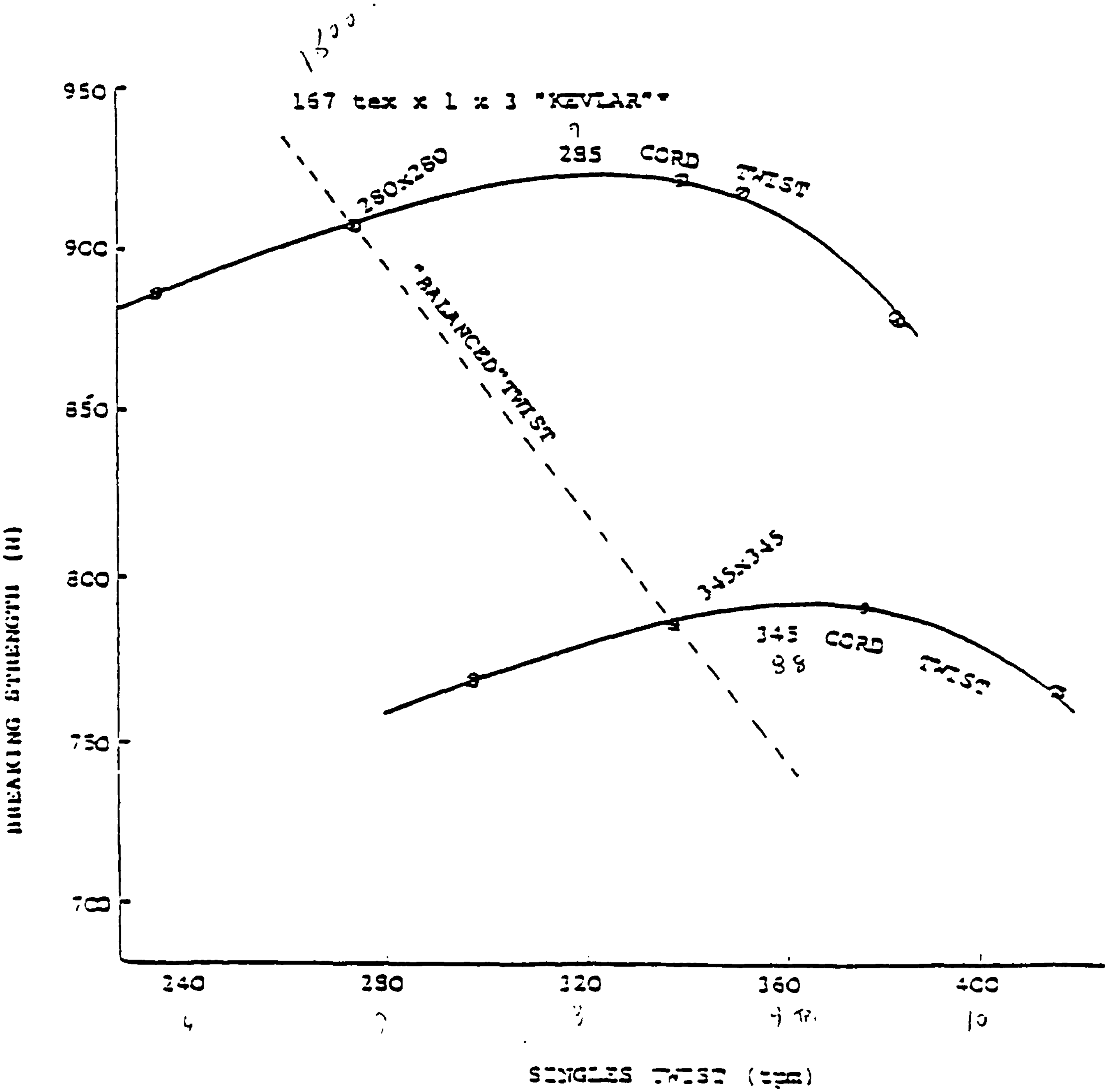
EFFECT OF TWIST ON DISC FATIGUE STRENGTH LOSS FOR KEVLAR®

(6% Extension Setting, 4 cN/tex)

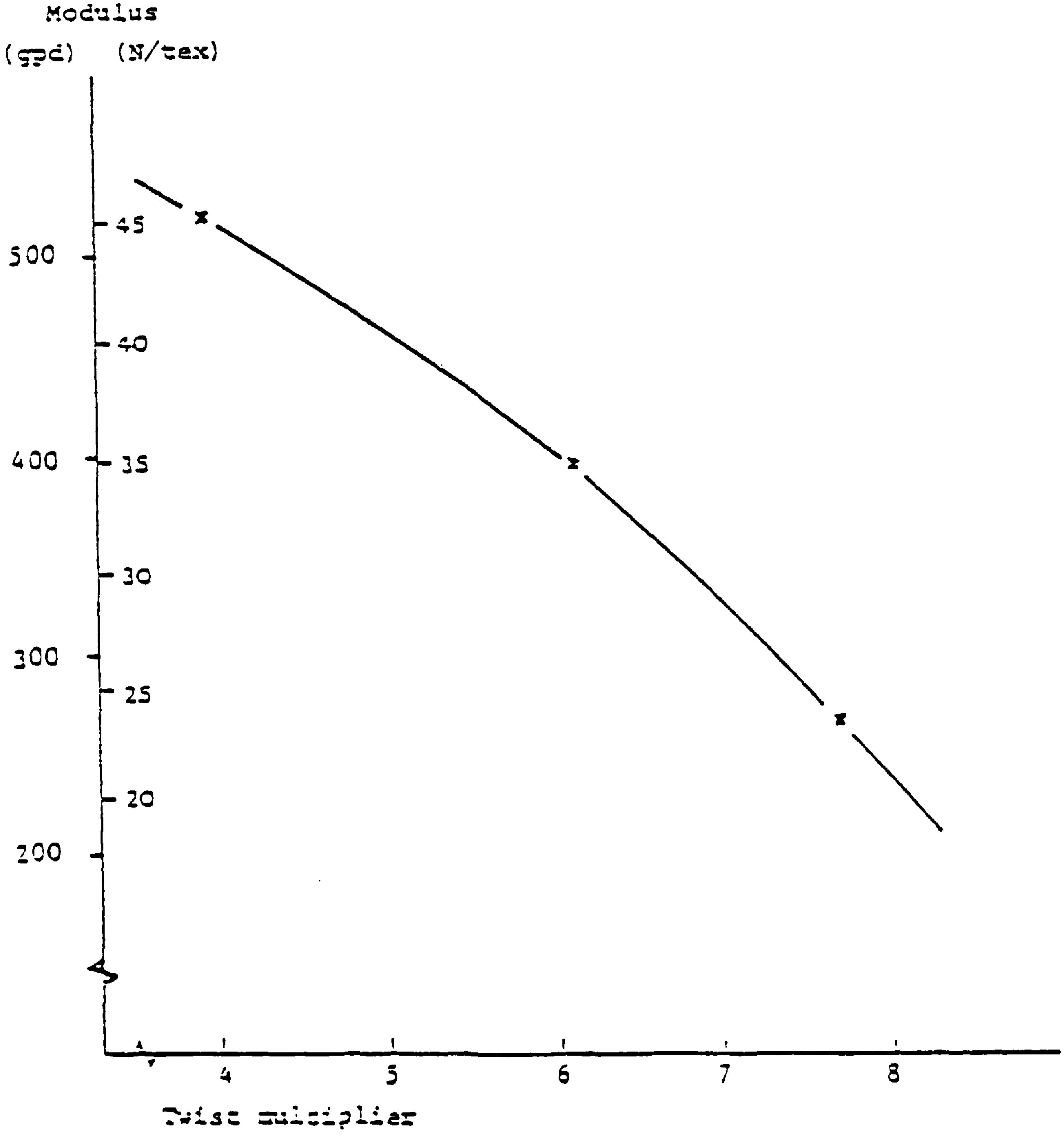


- Proper twist levels can multiply the effects of compressive stress by reducing buckling and flex.

EFFECT OF OFF-BALANCE TWIST ON CORD BREAKING STRENGTH



CORD MODULUS VERSUS TWIST MULTIPLIER



KEVLAR®
Aramid

Bulletin K-4

August 1979

Du Pont

TECHNICAL INFORMATION

Fibers

TEXTILE FIBERS DEPARTMENT
TECHNICAL SERVICE SECTION
E. I. DU PONT DE NEMOURS & CO. (INC.)

PROPERTIES OF INDUSTRIAL FILAMENT YARNS OF KEVLAR® ARAMID FIBER FOR TIRES, HOSE & RUBBERIZED BELTING

(Replaces Bulletin K-1 which should be destroyed)

A Du Pont fiber with a combination of physical and thermal properties-superior to those of other industrial filament yarns is discussed. Fiber properties and processing conditions are presented.

KEVLAR* aramid is an organic fiber that was developed by Du Pont within the family of aromatic polyamides. KEVLAR has a unique combination of high strength, high modulus, toughness, and thermal stability which provides an excellent opportunity for increasing the strength and/or reducing the weight of *reinforcement* for tires, hose, belting and other mechanical rubber-goods. Due to the distinct and different chemical composition and properties of aromatic polyamides, the Federal Trade Commission established the generic fiber classification, aramid**, to distinguish these fibers from other man-made fibers.

YARN PROPERTIES

Typical properties for unscoured yarn samples of KEVLAR are shown in Table I. Stress-stain curves of KEVLAR and other industrial filament yarns are presented in Figure 1.

These displays show that KEVLAR aramid yarn has:

- A breaking tenacity of 22.0 grams/denier (194.2 cN/tex) which is more than 5 times as strong as steel wire and twice that of industrial yarns of nylon, polyester or fiberglass as used in tires and mechanical rubber goods.
- An unusually high initial modulus of 525 grams/denier (4636 cN/tex), which is about twice that of steel wire, four times that of high tenacity polyester and nine times that of high tenacity nylon.
- Excellent thermal stability (retains 84% of its strength after 48 hours in dry air at 350°F or 177°C).

TABLE I

TYPICAL PROPERTIES OF KEVLAR® ARAMID YARN

Denier (dtex)	1500* (1670)
Number of Filaments	1000
Specific Gravity	1.44
Moisture Regain (commercial), %	7.0
Stress-Strain Properties	
Straight tests on conditioned yarn	
Breaking strength, lbs (daN)	72.8 (32.3)
Breaking tenacity, gpd (cN/tex)	22.0 (194.2)
Elongation at break, %	3.6
Initial modulus, gpd (cN/tex)	525 (4636)
Loop tests on conditioned yarn	
Breaking strength, lbs (daN)	70.0 (31.1)
Breaking tenacity, gpd (cN/tex)	10.5 (92.7)
Elongation at break, %	2.3
Thermal Properties	
Strength loss, %, after 48 hours in dry air at 350°F (177°C)	16
Shrinkage, %, in dry air at 320°F (160°C)	0.2
Zero-strength temperature** °F (°C)	850 (455)
Half-strength temperature, °F (°C)	750 (400)
Specific heat cal/g/°C at 25°C (J/kg K)	0.4 (1.6376 x 10[illegible])
Thermal conductivity BTU/hr/ft²/°F per inch of thickness (W/m K)	0.3 (0.0144)

*Other deniers (dtex) are also produced

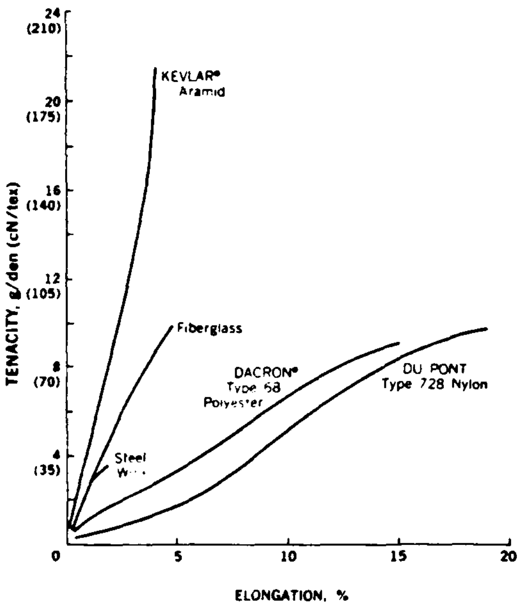
**Temperature at which the yarn breaks under a load of 0.1 g/denier (0.88 cN/tex)

*Registered Du Pont trademark

**In addition to KEVLAR, NOMEX* is also included in this generic fiber category. (See Du Pont bulletin entitled "Properties of NOMEX* Aramid Fiber")

FIGURE 1

STRESS-STRAIN CURVES FOR INDUSTRIAL FILAMENT YARNS



- A very low breaking elongation (3.6%), which is comparable to that of wire (2%).

EFFECTS OF RELATIVE HUMIDITY

KEVLAR is quite insensitive to changes in relative humidity. A slight loss in tenacity, as well as minute changes in fiber length and cross-section, can be measured by laboratory techniques at very high levels of relative humidity; but these effects are not permanent.

EFFECTS OF AIR TEMPERATURE

Figures 2 and 3 show the breaking tenacity and initial modulus of KEVLAR, industrial nylon, polyester, and wire in air at elevated temperatures after 3 minutes of exposure. The breaking tenacity of KEVLAR at 500° F (260° C) exceeds that of the other three yarns at room temperature, and the initial modulus of KEVLAR at 300° F (149° C) is more than 3 times that of polyester and nylon fibers at room temperature, and almost twice that of wire at 300° F (149° C).

CHEMICAL RESISTANCE

The effect of chemical agents on the breaking strength of KEVLAR aramid fiber is shown in Table II. Briefly:

- Strong acids and bases attack KEVLAR at elevated temperatures or at high concentrations.

FIGURE 2

BREAKING TENACITY OF INDUSTRIAL FILAMENT YARNS IN AIR AT ELEVATED TEMPERATURES

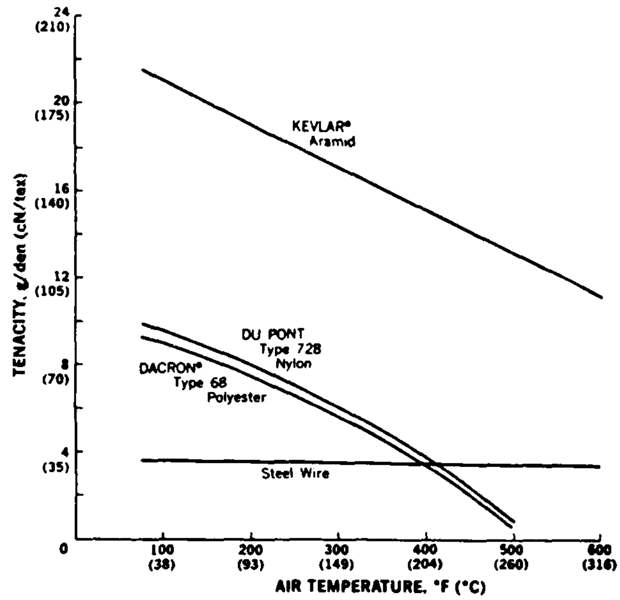


FIGURE 3

INITIAL MODULUS OF INDUSTRIAL FILAMENT YARNS IN AIR AT ELEVATED TEMPERATURES

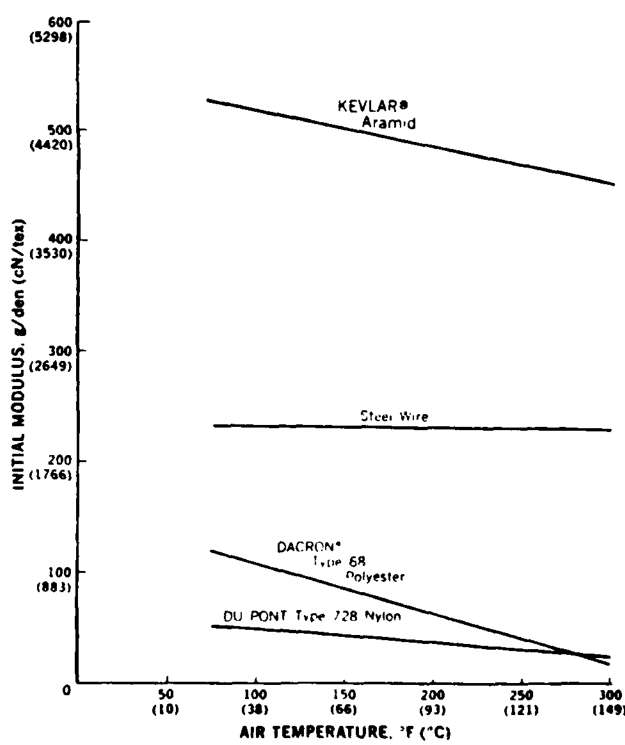


TABLE II

CHEMICAL RESISTANCE OF KEVLAR® ARAMID FIBER

Chemical	Concentration %	Temp. °F (°C)	Time (Hrs.)	Effect on Breaking Strength* None	Slight	Moderate	Appreciable	Degraded
ACIDS								
Hydrochloric	10	160 (71)	10					X
Sulfuric	10	70 (21)	100		X			
Sulfuric	70	70 (21)	100		X			
Sulfuric	10	210 (99)	10				X	
Nitric	1	70 (21)	100		X			
Nitric	10	70 (21)	100					X
Phosphoric	10	70 (21)	100	X				
Phosphoric	10	70 (21)	1000		X			
Phosphoric	10	210 (99)	100				X	
Acetic	40	70 (21)	1000		X			
Acetic	40	210 (99)	100				X	
Formic	90	70 (21)	100		X			
Formic	40	70 (21)	1000			X		
Formic	90	210 (99)	100				X	
ALKALIS								
Sodium Hydroxide	40	70 (21)	100	X				
Sodium Hydroxide	10	210 (99)	10					X
Ammonium Hydroxide	28	70 (21)	1000	X				
SALT SOLUTIONS								
Sodium Chloride	3	70 (21)	1000	X				
Sodium Chloride	10	210 (99)	100	X				
Sodium Chloride	10	250 (121)	100				X	
Sodium Phosphate	5	210 (99)	100			X		
MISCELLANEOUS CHEMICALS								
Formaldehyde in Water	10	70 (21)	1000	X				
Benzaldehyde	100	70 (21)	1000	X				
Cottonseed Oil	100	70 (21)	1000	X				
Linseed Oil	100	70 (21)	1000	X				
Phenol in Water	5	70 (21)	10	X				
Resorcinol	100	70 (21)	10	X				
Mineral Oil	100	210 (99)	10	X				
Water	100	210 (99)	100	X				
Lubrication Greases	100	70 (21)	1000	X				
Brake Fluid	100	Boil	100			X		
ORGANIC CHEMICALS								
Acetone	100	Boil	100	X				
Amyl Alcohol	100	70 (21)	1000	X				
Benzene	100	70 (21)	1000	X				
Carbon Tetrachloride	100	Boil	100	X				
Ether	100	70 (21)	1000	X				
Ethyl Alcohol	100	170 (77)	100	X				
Ethylene Glycol	50	210 (99)	1000				X	
FREON** 113	100	70 (21)	100					X
Gasoline, Leaded	100	70 (21)	1000	X				
Methyl Alcohol	100	70 (21)	1000	X				

*None ... 0 to 10% strength loss
Slight ... 11 to 20% strength loss
Moderate ... 21 to 40% strength loss
Appreciable ... 41 to 80% strength loss
Degraded ... 81 to 100% strength loss

**Du Pont registered trademark for fluorocarbon products

- Most organic solvents have little effect.

Under extreme conditions, free radicals can attack KEVLAR. No more than a 5% strength loss occurs when an RFL (resorcinol/formaldehyde & latex) dipped cord of KEVLAR is cured in normal rubber compounds.

YARN PROCESSING

KEVLAR yarn can be successfully processed on standard textile equipment. Some twisting recommendations are:

- Conventional twisters at speeds up to 6000 rpm
- Balloon tensions between 0.12 and 0.15 gram/denier (10.6 and 13.2 mN/tex) for ply and cable twisting.
- Special care should be taken when parallel plying two or more yarns for heavier singles yarn to insure equal or uniform tension is maintained as the break elongation of the yarn is very low.
- Matte-finished chrome or hard-ceramic guides and tension discs. (Polished chrome guides may abrade the yarn).
- Use nylon travelers — inspect regularly for cutting.
- Steel cot rolls are preferred, but elastomer covers have been used successfully.
- Spacing between yarns — "A" frame standards with yarn guides at midway points on the twisters are recommended for individual yarn separation between the beam let off and the extreme ends of the twisters.

TESTING TECHNIQUES

For "Instron" testing twist yarn samples with a 1.1 twist multiplier*, condition and test at 75°F (24°C) and 55% relative humidity. "Instron" 4-C air-actuated clamps at an air pressure of 70 psi (482.3 kPa) are required to prevent sample slippage during testing. The rate of extension during testing of KEVLAR aramid fiber should be half that specified for industrial filament yarn (ASTM** Test Method D-885) since the rate of response of the test equipment may be too slow for this high modulus fiber. Apply the same conditions for cord testing except use "Instron" 4-D clamps and rosin coat the cord specimen in the clamp area to minimize slippage.

SAFETY PRECAUTIONS

Toxicology

No evidence of skin sensitization was found when KEVLAR was tested on guinea-pig skin under occluded conditions or in a 200-subject prophetic patch-test on human skin. In the human patch-test, no skin irritation was observed after 48 hours of continuous contact. Some irritation, probably from mechanical causes, was observed after 144 hours of continuous occluded contact. No adverse mechanical or chemical induced skin-effects are expected from the usual industrial handling of KEVLAR aramid.

In a few processing operations, "fly" may be generated. Generally, the material which can be seen will "fall out" and not remain airborne and is outside the size range considered respirable. Our investigation of the respirable size material has led to two conclusions:

1. Concentration of elongated particles and total dust were low as compared to existing standards for nuisance and allergenic dust, and were in the range of the standards for fibrogenic dust§; and
2. Based on animal insufflation tests, respirable dust from KEVLAR produces what would be considered a typical lung reaction to a nuisance dust particulate.

Therefore, neither small amounts of fiber fly nor the other materials on the fiber should be present in the atmosphere in sufficient concentration to constitute a health problem. However, each company should check its own operations to establish their safety. As with any fibrous material, exposure by inhalation should be controlled by use of good industrial hygiene practice (e.g.; adequate ventilation).

Cutting & Splicing

Because of its unusually high strength and cutting resistance, caution should be exercised in splicing, handling, or cutting KEVLAR aramid. Manual cutting and splicing should be attempted only with stationary yarns to avoid possible injury from entanglement in moving yarn or fabric.

*Twist Multiplier = $\frac{\text{turns per inch} \times \sqrt{\text{denier}}}{73}$ $\left(= \frac{\text{turns per meter} \times \sqrt{\text{tex}}}{960}\right)$

**American Society for Testing and Materials, Philadelphia, PA

§Concentration was in this range in only one of the operations surveyed, all others were below the standard for fibrogenic dust

We believe that this information is the best currently available on the subject. It is offered as a possibly helpful suggestion in experimentation you may care to undertake along these lines. It is subject to revision as additional knowledge and experience are gained. Du Pont makes no guarantee of results and assumes no obligation or liability whatsoever in connection with this information. Anyone intending to use recommendations contained in this publication concerning equipment, processing techniques, or chemical products should first satisfy himself that the recommendations are suitable for his use and meet all appropriate safety and health standards. This publication is not a license to operate under, or intended to suggest infringement of, any existing patents.

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Properties and uses of KEVLAR® 29 aramid and KEVLAR® 49 aramid in Electromechanical Cables and Fiber Optics

Information Bulletin K-506A
June, 1980

C-59

DU PONT

KEVLAR* is the trademark for Du Pont's high strength, high modulus aramid fibers. KEVLAR does not melt or support combustion and has:

- very high strength to weight ratio
- good stretch resistance (modulus)
- low creep
- excellent fatigue life
- wide useful temperature range
- electrical non-conductivity
- outstanding environmental and chemical resistance
- corrosion resistance

This combination of properties has led to the adoption of KEVLAR in:

- data and sonabuoy mooring cables
- air and sea towed antennae
- acoustic arrays
- deep ocean work-system cables
- subsea television cables
- balloon tethers
- fiber optic cables

Product availability

Regular modulus KEVLAR 29 and extra high modulus KEVLAR 49 fibers are available as multifilament yarns in a number of yarn sizes.

KEVLAR 29:
Yarns (denier): 200, 400, 1000, 1500
(decitex): 222, 444, 1110, 1670
Rovings (denier): 9000, 15000
(decitex): 10000, 16670

KEVLAR 49:
Yarns (denier): 195, 380, 1140, 1420, 2130
(decitex): 217, 422, 1267, 1578, 2367
Rovings (denier): 4560, 7100
(decitex): 5067, 7889

All yarns of KEVLAR 29 and KEVLAR 49, as well as rovings of KEVLAR 29, are available with a standard finish to aid processing. Yarns and rovings are also available with no applied finish for cable applications such as fiber optics. Moreover, KEVLAR 29 (1500 and 15000 deniers) and KEVLAR 49 (1420 and 2130 deniers) are also available with a special high lubricity finish for improved abrasion resistance for cable applications.

*Du Pont Registered Trademark

Fiber properties

Typical physical properties of KEVLAR 29 and KEVLAR 49 compared with steel are shown in Table I.

TABLE I

Property	Unit	KEVLAR 29	KEVLAR 49	GIPS WIRE
Tensile Strength**	lb/in²	400.000	400,000	285,000
	(MPa)*	(2,760)	(2,760)	(1,960)
Modulus	lb/in²	9 x 10⁶	18 x 10⁶	29 x 10⁶
	(MPa)*	(62,000)	(124,110)	(200,000)
Density	g/cm³	1.44	1.44	7.86
Elongation at break**	%	3.6	2.4	1.1
Filament diameter inch		0.000478	0.000474***	0.020
	(mm)	(0.01214)	(0.01204)	(0.508)

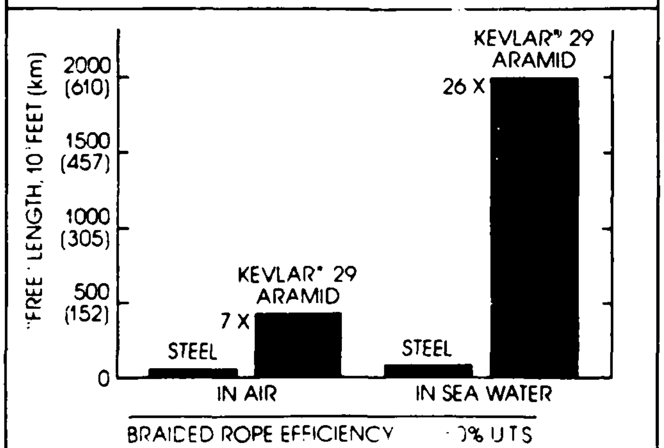
*MPa = MN/m² = lb/in.² x 6.89 x 10⁻³
**Twisted yarn – ASTM D2256 (KEVLAR), single wire (GIPS)
***Except 2130 denier – filament diameter = 0.0005096 inch
GIPS – galvanized improved plow steel
NOTE These properties are nominal values as tested by a specific method and are not for use as product specifications.

1.1 Strength

Yarns of KEVLAR are delivered without any twist. To obtain the optimum strength a 1.1 twist multiplier must be added to the yarn as given by:

$$\text{turns per inch} = \frac{80.3}{\sqrt{\text{denier}}}$$

Figure 1
"Free" Length Comparison
(Length at which Strength Member Breaks of Its Own Weight = Tensile Strength / Density)



Primary advantages of KEVLAR are very high strength per unit weight and low stretch. With the highest specific strength (strength/density) of any commercially available fiber, and its good resistance to stretch, KEVLAR offers the cable producer designs which can withstand increased payloads (or extend depth capabilities), yet permit easier handling with smaller, lighter and more economical systems.

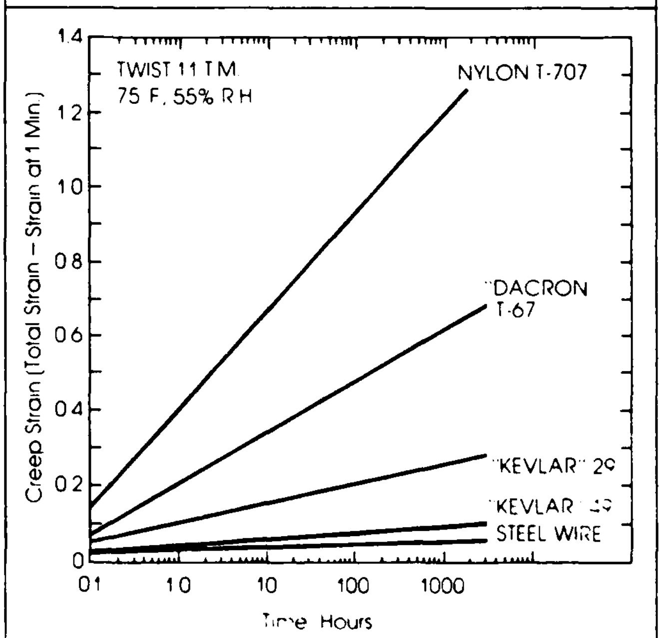
Figure 1 illustrates the "free" length which KEVLAR will support in both air and water compared to steel wire.

1.2 Creep under load

Compared with other organic fibers, the creep rates of both KEVLAR 29 and KEVLAR 49 are low and approach that of steel. At loads between 20% and 50% of ultimate break strength the creep rate of both KEVLAR 29 and 49 is relatively insensitive to load. The creep of KEVLAR 29 and KEVLAR 49 is a logarithmic function with time. At room temperature KEVLAR 49 shows a creep rate of approximately 40% that of KEVLAR 29 (0.02%/decade vs. 0.052%/decade).

Figure 2 compares the creep at 50% of ultimate breaking strength of a number of materials.

Figure 2
Creep at 50% Ultimate Break Strength

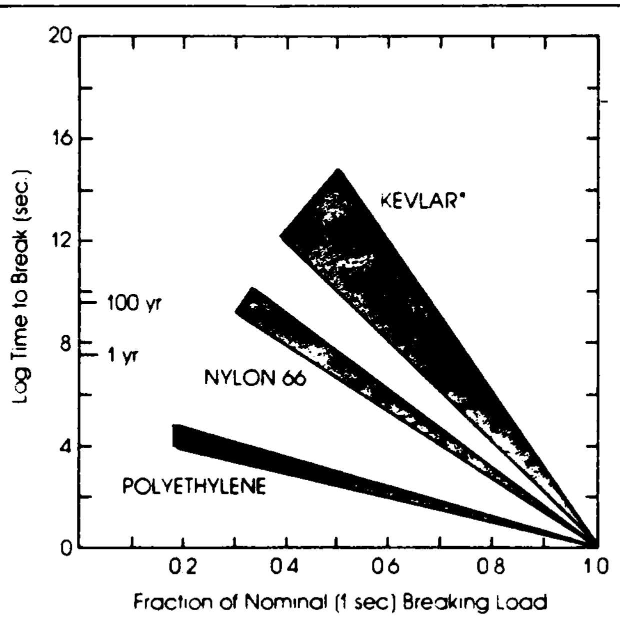


1.3 Tensile strength under load

Yarns of KEVLAR 29 and 49 will support a large fraction of their ultimate tensile strength for long periods of time. The time to failure under dead weight loading (stress rupture) for yarns of KEVLAR 29 and KEVLAR 49 as compared to nylon and polyethylene is shown in Figure 3.

Creep and stress-rupture characteristics may not be translated directly in ropes and cables due to a number of factors, such as added yarn twist, braid or lay angles, etc. The results shown here represent the optimum that can be expected from yarn and indicate that KEVLAR 29 and KEVLAR 49 fibers inherently have low creep and good stress-rupture properties.

Figure 3
Tensile Strength
vs.
Time Under Fixed Load

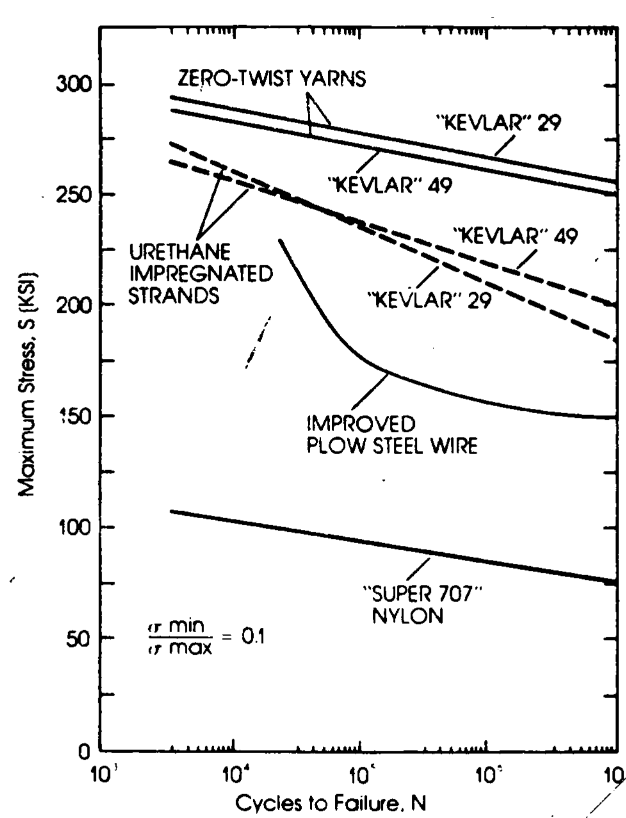


1.4 Tension - tension fatigue

Since most electromechanical cables are subject to fluctuating loads during their lifetime, good tension - tension fatigue performance is important. KEVLAR 29 and 49 have superior fatigue resistance to steel wire and many organic yarns.

Figure 4 compares the tension - tension fatigue of KEVLAR 29 and KEVLAR 49 versus steel wire and nylon.

Figure 4
Tension - Tension Fatigue

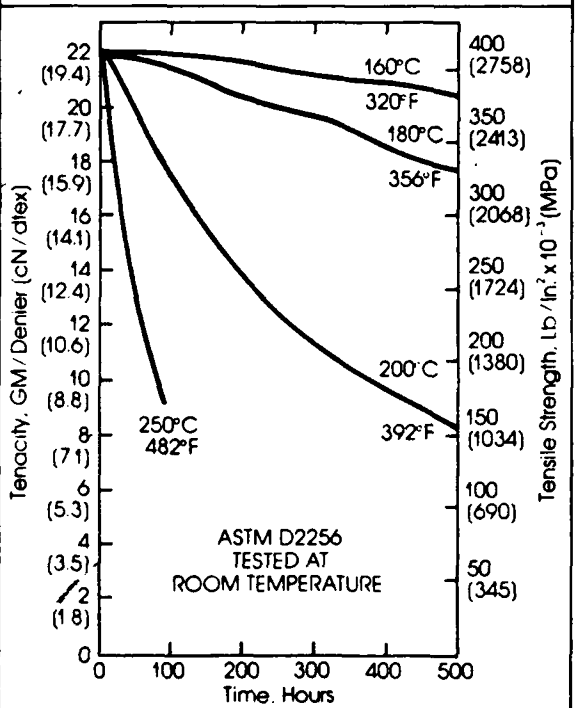


2. Thermal characteristics

Both KEVLAR 29 and KEVLAR 49 have good thermal stability retaining a high percentage of their properties up to 180°C. Since KEVLAR does not melt or support combustion, short term exposure to temperatures in excess of 300°C has little effect on strength. At cryogenic temperatures (−170°C) KEVLAR does not embrittle and maintains its properties. The longitudinal thermal coefficient of expansion is -1.1×10^{-6}/°F (-2×10^{-6}/°C) between 0–100°C and -2.2×10^{-6}/°F (-4×10^{-6}/°C) between 100–200°C.

Figure 5 shows the effect of temperature on the tensile strength of KEVLAR 29 (essentially the same for KEVLAR 49).

Figure 5
The Effect of Temperature on the Tensile Strength of KEVLAR 29 Aramid



3. Chemical resistance

The chemical resistance of both KEVLAR 29 and 49 are excellent except in most strong acids and bases. Table 2 shows the effect of a number of chemicals on the tensile strength of KEVLAR.

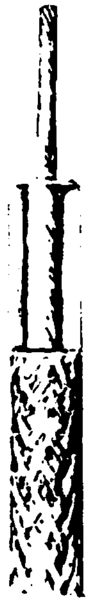


TABLE II
Chemical Resistance of KEVLAR

Chemical	Conc %	Temp °C	Time hrs.	Strength Loss, % KEVLAR 29	Strength Loss, % KEVLAR 49
Hydrochloric Acid	37	21	100	72	63
Hydrochloric Acid	37	21	1000	88	81
Hydrofluoric Acid	10	21	100	10	6
Nitric Acid	1	21	100	16	5
Nitric Acid	10	21	100	79	77
Sulfuric Acid	10	21	100	9	12
Sulfuric Acid	10	21	1000	59	31
Sodium Hydroxide	10	21	1000	74	53
Ammonium Hydroxide	28	21	1000	9	7
Acetone	100	21	1000	3	1
Dimethyl Formamide	100	21	1000	0	0
Methyl Ethyl Ketone	100	21	24	*	0
Trichloroethylene	100	21	24	*	1.5
Trichloroethylene	100	88	387	7	*
Ethyl Alcohol	100	21	1000	1	0
Jet Fuel (JP-4)	100	21	300	0	4.5
Jet Fuel (JP-4)	100	200	100	4	*
Brake Fluid	100	21	312	2	*
Brake Fluid	100	113	100	33	*
Transformer Oil (Texaco #55)	100	60	500	4.6	0
Kerosene	100	60	500	9.9	0
Freon† 11	100	60	500	0	2.7
Freon† 22	100	60	500	0	3.6
Tap Water	100	100	100	0	2
Sea Water (Ocean City, N.J.)	100	*	1 yr.	1.5	1.5
Water at 10,000 psi	100	21	720	0	*
Water – Superheated	100	138	40	9.3	*
Steam – Saturated	100	150	48	28	*

*Indicates data not available
† DuPont registered trademark for fluorocarbon

Tests indicate that long term static loading in sea-water (3 years) causes no significant loss in strength of KEVLAR 29 and KEVLAR 49.

Yarns of KEVLAR 29 and 49 are subject to degradation on exposure to UV radiation. For this reason, jacketing is recommended. The most effective jacket is one made from an impervious material such as extruded plastic, although a braided jacket can also provide adequate protection.

4. Utilization

For the most efficient design of the strength member for an electromechanical cable, it is necessary to predict the motions and loads of the cable as well as the degree of repeated flexing of the cables under load over sheaves. Also, as longer cables are required, the self-weight of the strength member limits the economically allowable safety factor.

The use of KEVLAR with its unique combination of high strength to weight ratio, and elastic modulus compatible with that of the conductors, allows new design concepts of cable previously thought unfeasible.

Yarns of KEVLAR can be used either as-is or as resin impregnated strands on conventional textile twisting, stranding, and braiding equipment. Yarns with a special lubricity finish available from Du Pont are usually selected when the cable is to be made directly from unimpregnated KEVLAR. Impregnated strands made with various resin compounds are available from several manufacturers* and should be selected on the basis of specific application.

It is recognized that while yarns of KEVLAR 29 and 49 either impregnated or unimpregnated can be used on standard equipment, care must be taken to achieve maximum efficiency. Since KEVLAR 29 and 49 do not plastically deform or yield like other synthetic fibers or steel wire, equal tension must be applied to all filaments during processing to obtain the best strength and modulus efficiency.

It has been shown that the best strength and lowest scatter in strength is achieved with process tensions of at least 0.05 grams/denier although acceptable results have been obtained with uniform tensions as low as 0.01 grams/denier. In addition, it is also significant to point out that polished chrome or brass guide surfaces can cause extensive damage to KEVLAR yarns. Where rolling guides cannot be used, the preferred guides are ceramic or matte chrome finish.

4.3 Cable designs

A wide variety of rope and cable designs using yarns of KEVLAR 29 and 49 have been demonstrated including 8-strand plaited, single and double braids, parallel strands, "wire rope" designs and center core and contra-helically wound cables. The choice of construction is made to achieve the optimum balance of strength, modulus and flexibility required for the specific application.

4.4 Terminations

Successful termination of ropes and cables of KEVLAR 29 and 49 have also been demonstrated with a variety of techniques. Specific applications may require design and technique modifications to obtain optimum results.

*(available on request)

PRODUCTS

KEVLAR 29

Denier*	Filaments	Available Types	Yield yd/lb.	Yield m/kg**	Nominal Yarn Dia. *** 10^{-3} in	Nominal Yarn Dia. *** mm	Min. Break Strength**** lbs.	Min. Break Strength**** kg.
200	134	964	22320	45000	7.8	0.20	8.0	3.6
400	267	964	11160	22500	11.0	0.28	19.0	8.6
1000	666	961	4464	9000	17.3	0.44	43.0	19.5
1500	1000	960 961	2976	6000	21.2	0.54	62.0	28.0
9000	6000	960 961	497	1000	52.0	1.32	360.0	163.3
15000	10000	960 961	298	600	67.1	1.70	615.0	278.9

Available Finish Types: 960 — Cordage Finish; 961/964-Standard Finish.

KEVLAR 49

Denier*	Filaments	Available Types	Yield yd/lb.	Yield m/kg**	Nominal Yarn Dia. *** 10^{-3} in	Nominal Yarn Dia. *** mm	Min. Break Strength**** lbs.	Min. Break Strength**** kg.
195	134	965, 968	22895	46155	7.7	0.20	7.7	3.49
380	267	965, 968	11749	23684	10.9	0.28	16.0	7.25
1140	768	965, 968	3916	7895	18.4	0.47	49.0	22.2
1420	1000	965, 968, 978	3144	6338	21.0	0.53	59.0	26.7
2130	1000	965, 968, 978	2097	4228	25.4	0.65	85.0	38.5
4560	3072	968	980	1973	36.8	0.93	250.0	113.4
7100	5000	968	630	1268	47.0	1.19	390.0	177.3

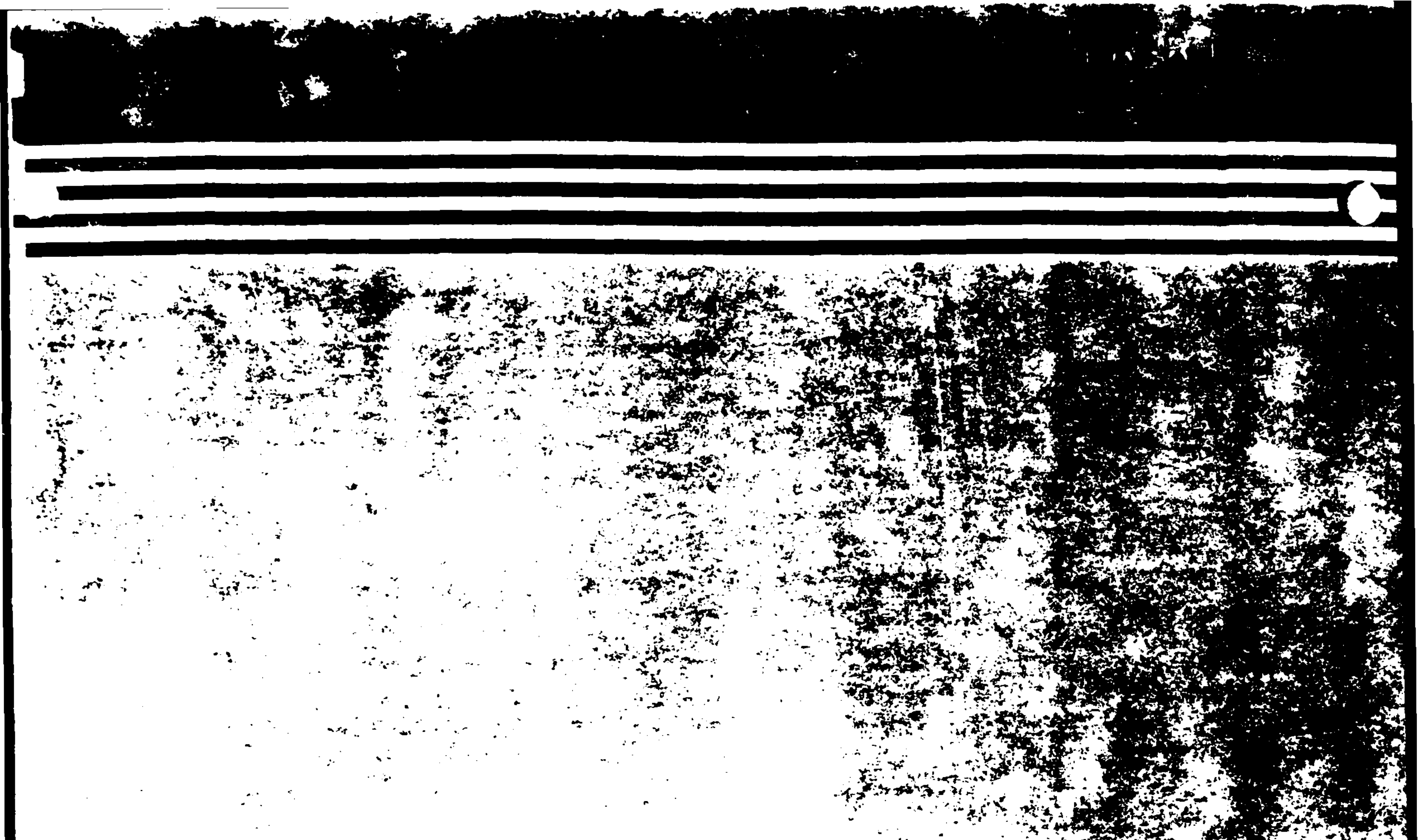
Available finish types: 965 — Standard Finish, 968 — No Applied Finish,
978 — Cordage Finish

*Denier is weight in grams of 9000 meters of yarn or roving

**m/Kg = yd/lb x 2.016

***Assuming 70% packing factor

****Yarn and rovings of KEVLAR 29 and yarns of KEVLAR 49 are conditioned for 3 hrs at 50°C followed by 14 hrs @ 25°C and 55% RH. Twist is applied prior to measurement as given by turns per inch = 80.3/ √ denier for yarns, and turns per inch = 91.25 / √ denier for rovings, respectively. Instron 4 D air operated clamps at 80 psi (551.6 KPa) pressure used to secure sample during testing, with elongation rate of 50%/minute for KEVLAR 29 and 10%/minute for KEVLAR 49. Rovings of KEVLAR 49 (4560 and 7100 deniers) are tested per ASTM D2343, the resin impregnated strand test, using a resin content of 65 + 5% by weight.



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DUPONT

PHYSICAL PROPERTIES AND CHEMICAL RESISTANCE

OF

KEVLAR®

CONVERSION FACTORS

gpd	dN/tex	psi	MPa
1	0.883	18,433	127
20	17.7	368,700	2540
500	442	9.2×10^6	68×10^3

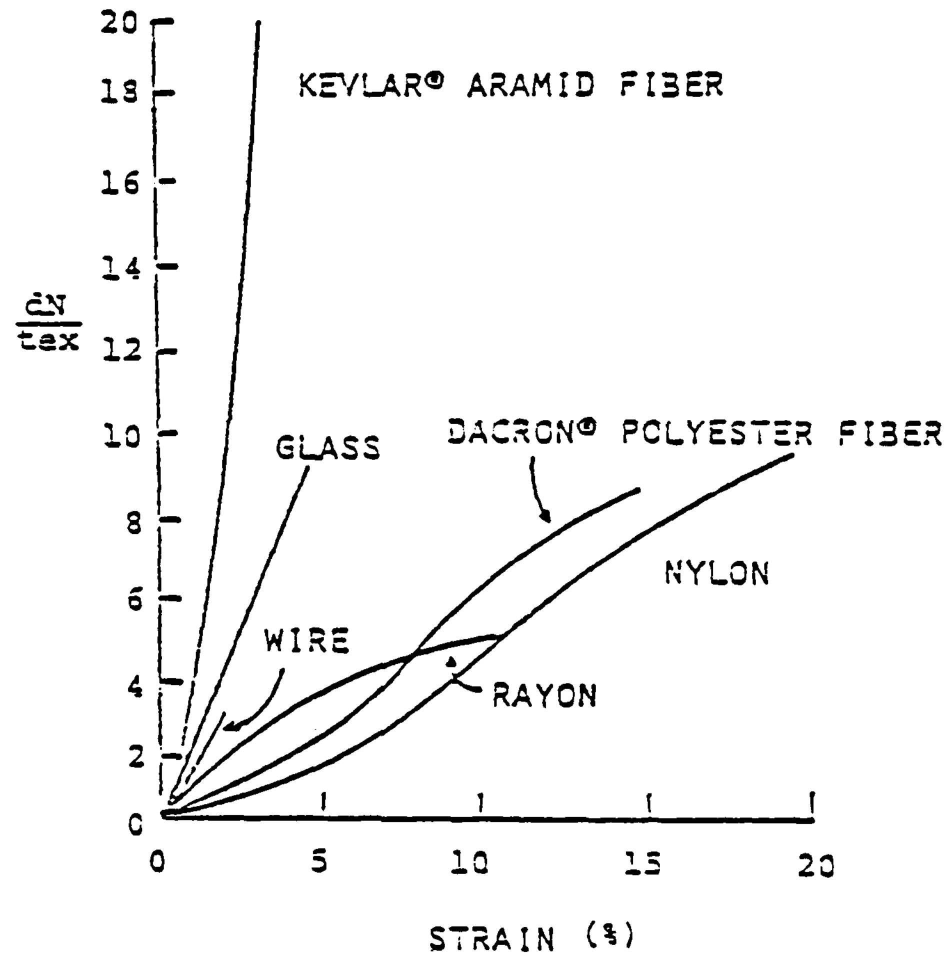
1 gpd = 12,801 X ρ psi

COMPARISON OF PHYSICAL PROPERTIES

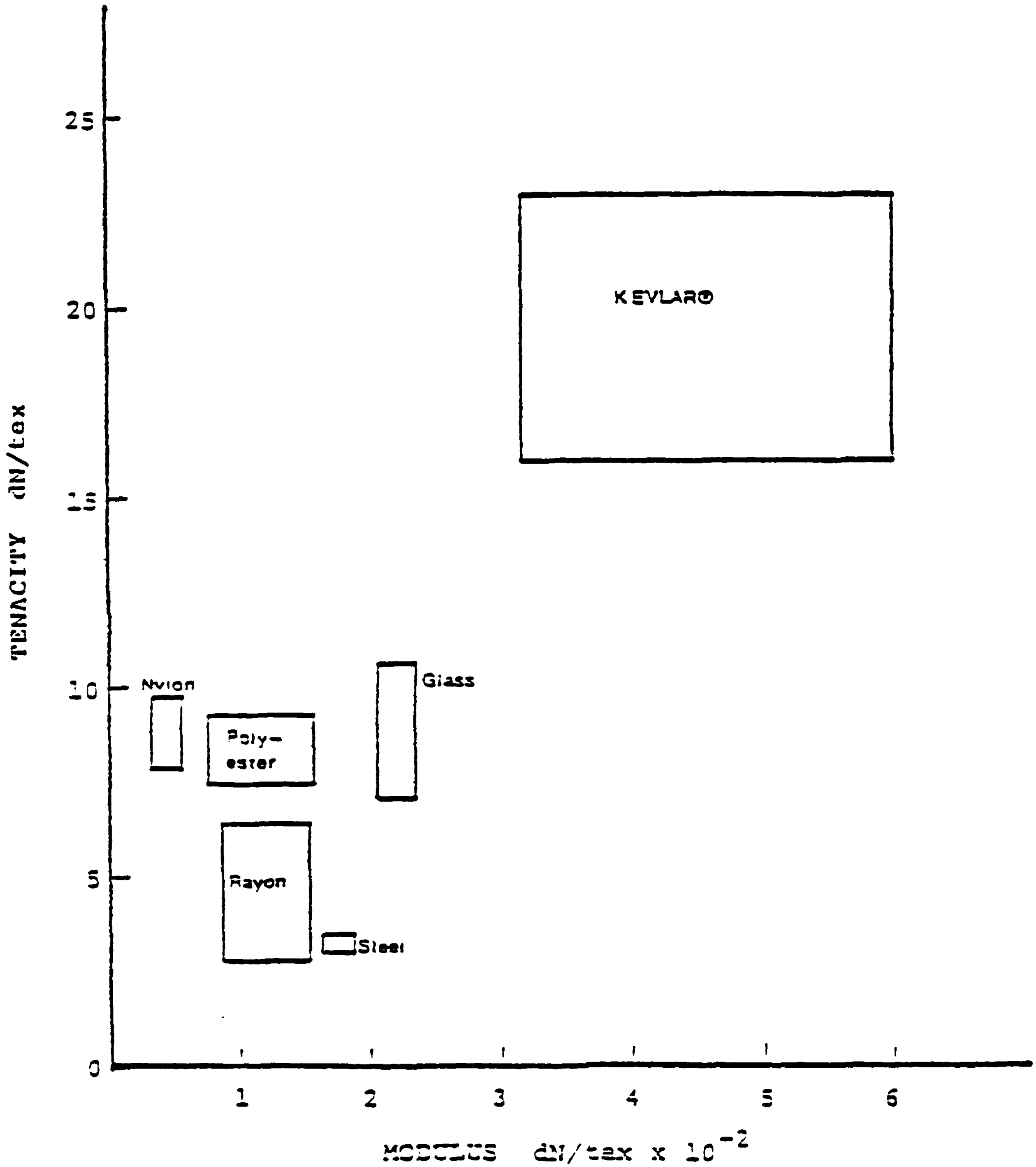
	m.p (°C)	Tg (°C)	ρ (g/cc)	T (dN/tex)	Eb (%)	M (dN/tex)
66 Nylon	250	50	1.14	8.4	20	44
Polyester	260	90	1.38	7.9	15	103
Glass	1200	-	2.25	7.9-11.0	45	265
Steel	1536	-	7.86	3.4	1.7	176
Rayon	~200	-	1.58	4.9	11	110
Nomex®	~370*	-	1.38	4.9	20	122
Kevlar®	~450*	-	1.44	20.3	4	485
Kevlar® 49	~450	-	1.44	19.4	4	750

* chars

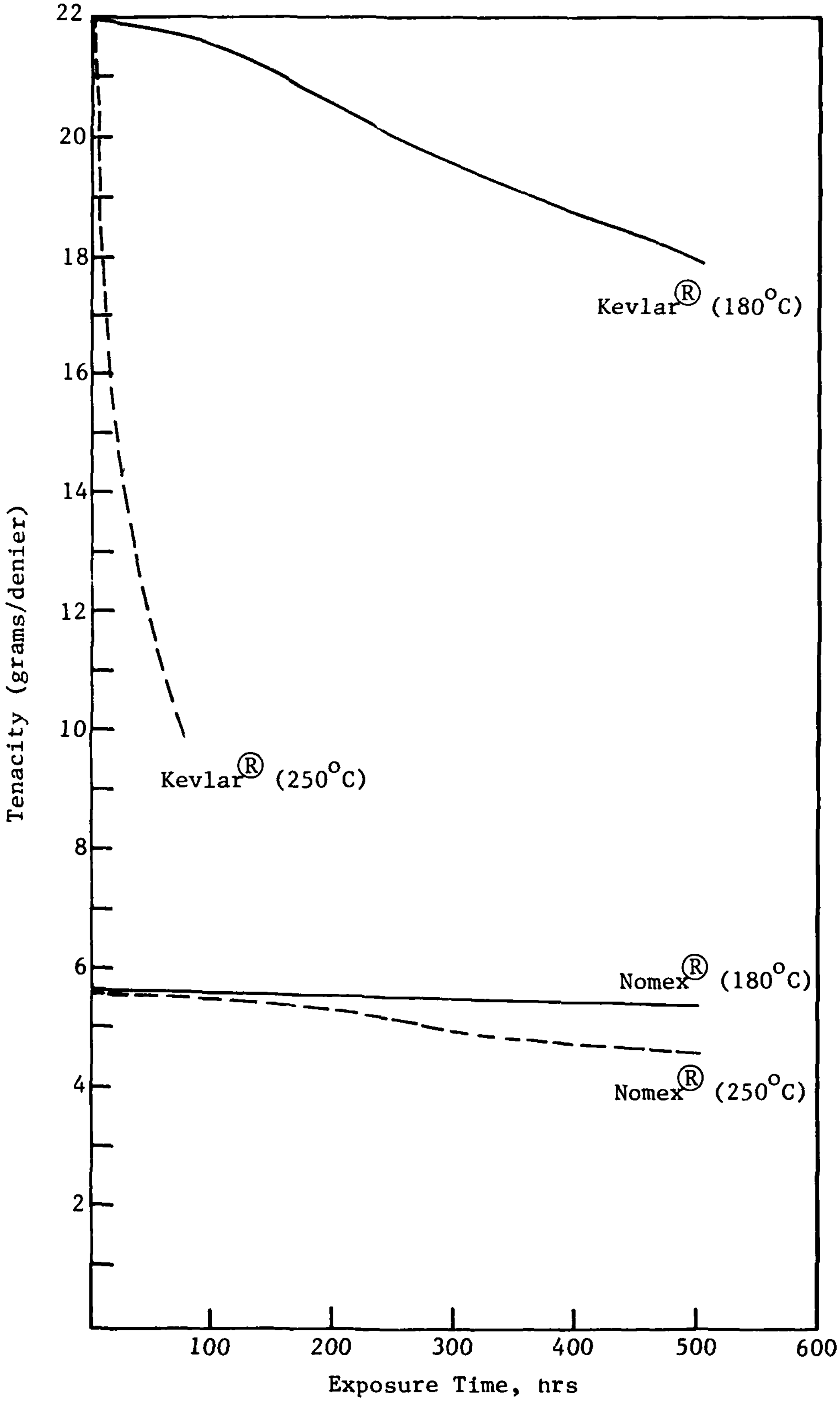
STRESS-STRAIN CURVES



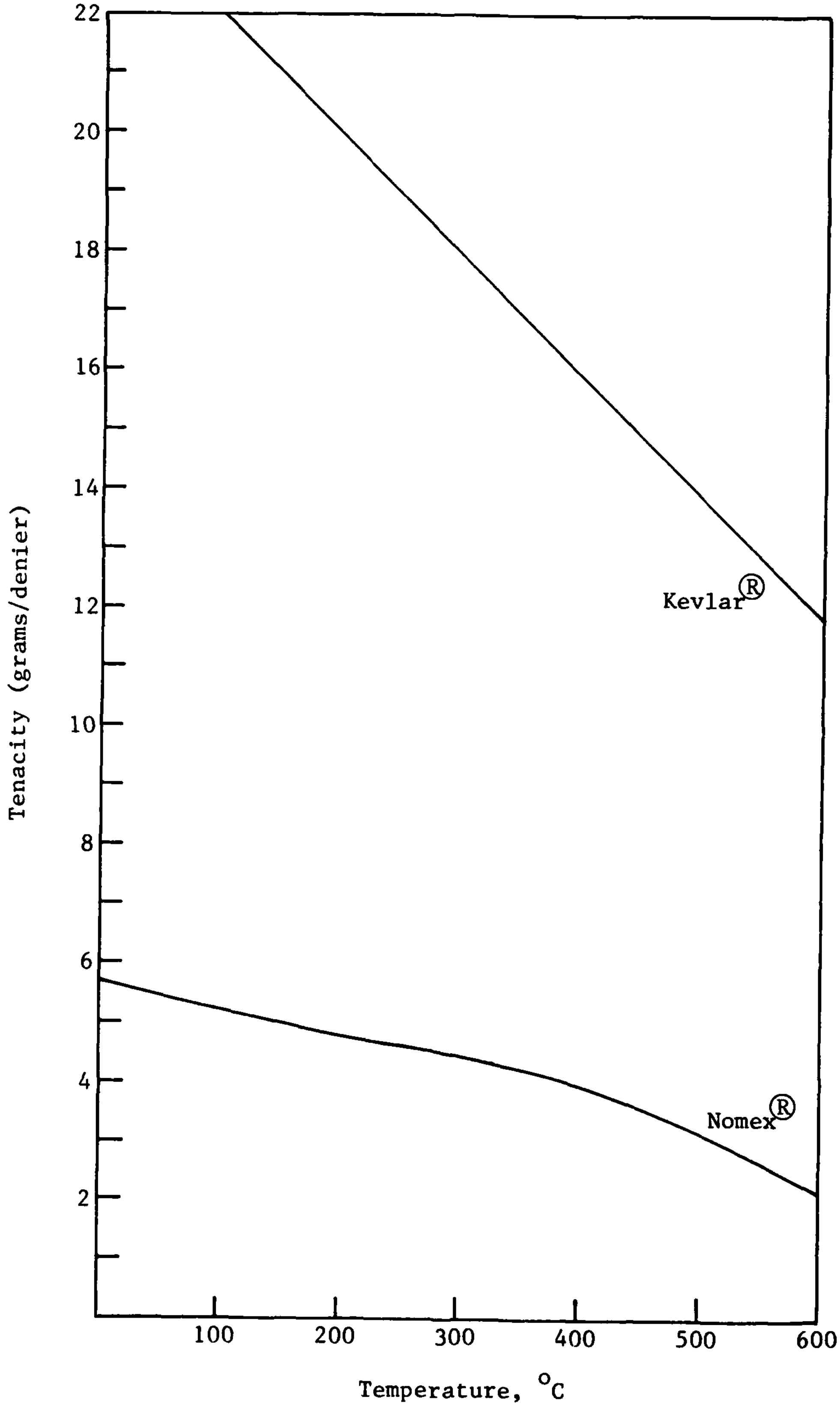
TENSILE STRENGTH - MODULUS RELATIONSHIP



- Kevlar® is in a unique area of the strength-modulus map.



EFFECT OF TEMPERATURE ON TENSILE STRENGTH
TESTED AT ROOM TEMPERATURE



Dry Twist - added yarn test - 10" gauge lengths 10%/min extension rate.

TESTED AT TEMPERATURE AFTER 5 MINUTES EXPOSURE

TABLE 1

	KEVLAR®		50/50	NYLON			NOMEX®		
	H_2O	P	P/H_2O	H_2O	P	P/H_2O	H_2O	P	P/H_2O
Initial	76.2	→	→	14.8	→	→	13.6	→	→
% Ret.	100	→	→	100	→	→	100	→	→
pH	-	-	9.70	-	-	9.70	-	-	9.70
7 Days, rm. temp.	74.2	73.7	-	14.2	14.2	-	12.5	12.9	-
% Ret.	97	97	-	96	96	-	92	95	-
pH	7.33	10.19	-	7.15	9.72	-	7.20	10.09	-
7 Days, 122°C	45.3	32.5	40.4	12.4	13.6	13.1	12.4	10.7	11.8
% Ret.	59	43	53	84	92	89	91	79	87
pH			8.33			8.35			8.21
14 Days, 122°C	23.3	37.9	30.0	7.2	13.2	12.5	12.5	10.6	11.7
% Ret.	31	50	39	49	89	84	92	78	86
pH			8.38			8.39			8.24
21 Days, 122°C	21.2	19.5	36.6	4.1	12.7	12.1	12.4	10.3	11.5
% Ret.	28	26	48	28	86	82	91	76	85
pH			8.30			8.30			8.33
28 Days, 122°C	14.3	29.6	23.8	3.6	12.2	11.7	12.0	9.9	11.8
% Ret.	19	39	31	24	82	79	88	73	87
pH	6.02	8.35	8.10	5.56	8.38	8.21	6.05	8.36	8.08

HYDROLYSIS RESISTANCE OF "KEVLAR" ARAMID

Superheated Water

(sealed in tube with water @ 280°F (138°C)

Hours Exposure	% Strength Loss
20	4.5
40	9.3
60	12.5
80	15.6

Saturated Steam

Autoclave at 20 PSIG, 250°F (121°C)

Hours Exposure	% Strength Loss
48	3 to 27
100	57 to 74

Water Below Boil

(water at 210°F [99°C])

Hours Exposure	% Strength Loss
100	0

Ethylene Glycol

(50/50 concentration @ 210°F)

	Hours Exposure	% Strength Loss
"Kevlar"	1000 hrs.	46 to 69.5
"Nomex"	1000 hrs.	14

W. P. Cooper
12/1/81

TENSILE PROPERTIES OF "KEVLAR" AT ARCTIC TEMPERATURES

	24°C	- 45°C
TENACITY, cN/TEX	169	175
TENSILE STRENGTH, DAN/CM^2	24260	25150
ELONGATION, %	4.1	3.9
MODULUS, cN/TEX	3750	4600
MODULUS, DAN/CM^2	540000	661000

TWISTED CORD OF KEVLAR*
6.5 TWIST MULTIPLIER
10% MIN. ELONGATION
25.4 CM GAGE LENGTH
TESTED AT TEMPERATURE

CHEMICAL RESISTANCE OF "KEVLAR" ARAMID FIBER

CHEMICAL	CONC., %	TEMP., °F (°C)	TIME (HRS.)	EFFECT ON BREAKING STRENGTH* NONE	SLIGHT	MOD.	APPREC.	DEGRADI
ACIDS								
HYDROCHLORIC	10	160(71)	10					X
HYDROCHLORIC	37	70	24				X	
HYDROCHLORIC	37	70	1,000					X
HYDROFLUORIC	10	70	100		X			
SULFURIC	10	70(21)	100		X			
SULFURIC	70	70(21)	100		X			
SULFURIC	10	210(99)	10				X	
NITRIC	1	70(21)	100		X			
NITRIC	10	70(21)	100					X
PHOSPHORIC	10	70(21)	100	X				
PHOSPHORIC	10	70(21)	1,000		X			
PHOSPHORIC	10	210(99)	100				X	
ACETIC	40	70(21)	1,000		X			
ACETIC	40	210(99)	100				X	
FORMIC	90	70(21)	100		X			
FORMIC	40	70(21)	1,000			X		
FORMIC	90	210(99)	100				X	

ALKALIS	CONC., %	TEMP., °F (°C)	TIME (HRS.)	EFFECT ON BREAKING STRENGTH* NONE	SLIGHT	MOD.	APPREC.	DEGRADED
SODIUM HYDROXIDE	40	70(21)	100	X				
SODIUM HYDROXIDE	10	210(99)	10					X
AMMONIUM HYDROXIDE	28	70(21)	1,000	X				
SALT SOLUTIONS								
SODIUM CHLORIDE	3	70(21)	1,000	X				
SODIUM CHLORIDE	10	210(99)	100	X				
SODIUM CHLORIDE	10	250(121)	100				X	
SODIUM PHOSPHATE	5	210(99)	100			X		
MISCELLANEOUS CHEMICALS								
FORMALDEHYDE IN WATER	10	70(21)	1,000	X				
BENZALDEHYDE	100	70(21)	1,000	X				
COTTONSEED OIL	100	70(21)	1,000	X				
LINSEED OIL	100	70(21)	1,000	X				
PHENOL IN WATER	5	70(21)	10	X				
RESORCINOL	100	70(21)	10	X				
MINERAL OIL	100	210(99)	10	X				
TRANSFORMER OIL (TEXACO #55)	100	140(60)	500	X				
WATER	100	210(99)	100	X				
WATER AT 20,000 PSI	100	70(21)	720	X				
WATER-SUPERHEATED	100	280(138)	40					
STEAM-SATURATED	100	300(149)	48			X		
SEA WATER (OCEAN CITY, NJ)	100	-	1 YEAR	X				
LUBRICATION GREASES	100	70(21)	1,000	X				
BRAKE FLUID	100	70(21)	312	X				
BRAKE FLUID	100	235(113)	100			X		

ORGANIC CHEMICALS	CONC., %	TEMP., °F (°C)	TIME (HRS.)	EFFECT ON BREAKING STRENGTH*				
				NONE	SLIGHT	MOD.	APPREC.	DEGRADED
ACETONE	100	70	24	X				
ACETONE	100	BOIL	100	X				
AMYL ALCOHOL	100	70(21)	1,000	X				
BENZENE	100	70(21)	1,000	X				
CARBON TETRACHLORIDE	100	BOIL	100	X				
ETHER	100	70(21)	1,000	X				
ETHYL ALCOHOL	100	70(21)	24	X				
ETHYL ALCOHOL	100	170(77)	100	X				
ETHYLENE GLYCOL	50	210(99)	1,000				X	
FREON® 11	100	140(60)	500	X				
FREON® 22	100	140(60)	500	X				
FREON® 113	100	70(21)	100	X				
FREON® 113	100	117(47)	166	X				
GASOLINE, LEADED	100	70(21)	1,000	X				
JET FUEL (JP-4)	100	70(21)	300	X				
JET FUEL (JP-4)	100	390(199)	100	X				
KEROSENE	100	140(60)	500	X				
METHYL ALCOHOL	100	70(21)	1,000	X				
TRICHLOROETHYLENE	100	190(88)	387	X				

* NONE.................... 0 TO 10% STRENGTH LOSS
SLIGHT.................. 11 TO 20% STRENGTH LOSS
MODERATE................ 21 TO 40% STRENGTH LOSS
APPRECIABLE............. 41 TO 80% STRENGTH LOSS
DEGRADED................ 81 TO 100% STRENGTH LOSS

Ingredients which were found to have no or negligible effect in actual rubber compounds

Natural rubber SS N° 1
SBR 1500
Nordel 1040
Neoprene GN
Adiprene®
Rubber process oils
Aromatic oils
Circo light process oils
Paraffinic oils
Stearic acid (and salts)
Zinc oxide
Carbon blacks
"Hi-Sil"
"Epon" 812
RF-resin
"Agerite" Resin D
Neozone® A
Neozone® D
Sulfur
MBTS
MBT
NOBS Special

Ingredients which were especially checked and were found to have no or minor effects*

Neoprene GN
Lubricating greases
DPG
TMTD
Methyl Zimate
Sulfur*
Stearic acid*
"Agerite" White
Retarder W
Diaryl-p-phenylene-diamines*
$ZnCl_2$
Linseed oil
Ethyl acetate
Aqueous phenol and resorcinol solution

Ingredients which have not been checked but should have little or no effect - by analogy

Natural Rubber SS N° 2
SBR
SBR 1712
Neoprene W
Neoprene WB
Vibrathan 5004
Sundex Oil N°790
Sunpar N°2280
Sunthene N°3120
Methyl Tuex
Sulfenamide types
Royalac N°133
Royalac N°139
Royalac N°140
Tetrone A
Tellurac
Sulfads
Zinc Oleate
Seedine
Durez 12687
Petrolatum
Paraffin wax
BLE-25
Octamine
Naugawhite
"Agerite" Superlite
Aranox
NBC
Calcium carbonate
Graphite
Calcium oxide
Sodium acetate

* An increase in strength was observed with these chemicals

ULTRAVIOLET STABILITY OF KEVLAR®

(FADE OMETER/XENON ARC)

HOURS EXPOSURE	% STRENGTH LOSS		
	4500 DENIER	3000 DENIER	1500 DENIER
450	36	48	64
900	53	58	77

CONCLUSION: DATA INDICATE SELF-SCREENING INFLUENCE OF OUTER LAYERS OF KEVLAR®

OZONE RESISTANCE

KEVLAR® AND T-728 NYLON YARNS EXPOSED TO 10 AND 100 PPHM O_2 FOR 8, 16, AND 24 HOURS.

	KEVLAR®	T728
AVERAGE STRENGTH GAIN:	1.8	0.1%
FREQUENCY OF STRENGTH GAIN:	83	50%

CONCLUSION: EFFECT OF OZONE INSIGNIFICANT

EFFECT OF HIGH ENERGY RADIATION

2 MEV ELECTRONS

RESONANT TRANSFORMER

EXPOSURE		YARN TENSILE				
MEGARADS	DEN	TEN (GPD)	ELON. (%)	MOD. (GPD)	B.S. KG	ηINH
100	1513	23.1	4.2	480	40.0	4.61
500	1505	22.9	4.2	480	34.5	4.78
0	1531	22.8	4.3	470	34.9	4.64

- NO APPRECIABLE CHANGES IN MOLECULAR WEIGHT OF POLYMER OR IN STRENGTH OF YARN.
- ADDITIONAL HEAT AGING EXPERIMENTS INDICATE THE ABSENCE OF TRAPPED RADICAL SPECIES THAT COULD LEAD TO CROSSLINKING OR PEROXIDE FORMATION.

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INSTRUCTIONS

The Naval Civil Engineering Laboratory has revised its primary distribution lists. The bottom of the label on the reverse side has several numbers listed. These numbers correspond to numbers assigned to the list of Subject Categories. Numbers on the label corresponding to those on the list indicate the subject category and type of documents you are presently receiving. If you are satisfied, throw this card away (or file it for later reference).

If you want to change what you are presently receiving:

- Delete - mark off number on bottom of label.
- Add - circle number on list.
- Remove my name from all your lists - check box on list.
- Change my address - line out incorrect line and write in correction **(DO NOT REMOVE LABEL).**
- Number of copies should be entered after the title of the subject categories you select.

Fold on line below and drop in the mail.

Note: Numbers on label but not listed on questionnaire are for NCEL use only, please ignore them.

Fold on line and staple.

DEPARTMENT OF THE NAVY

Naval Civil Engineering Laboratory
Port Hueneme, CA 93043-5003

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